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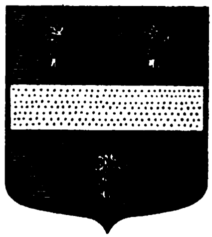
SOILS AND MANURES

E. J. Russell

William S. Noblitt



Noblitt

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Cambridge Farm Institute Series

General Editors:

T. B. Wood, M.A.

E. J. Russell, D.Sc.

A STUDENT'S BOOK ON SOILS AND MANURES

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A STUDENT'S BOOK
ON
SOILS AND MANURES

BY

E. J. RUSSELL, D.Sc.

DIRECTOR OF THE ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN

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PREFACE

WHATEVER kind of farming a man is going in for, he depends in the last instance either on his own soil or on somebody else's, and unless he thoroughly understands the principles of soil management he will not be very successful in the crop production part of his work. These principles can of course be acquired by experience, but the process is likely to be costly, and the young farmer of to-day is invited to attend Farm Institutes or Colleges where he can be taught them and be thus spared some of the bitterness of the older method. By learning something about the soil and about fertilisers he will be in a position to attain greater success in his farming.

But the man who simply studies the subject to make a little more money will miss nine-tenths of the pleasure of the work and of the joy of farming. The soil is to be regarded not simply as a mine out of which a little wealth may be extracted, but as a part of Nature, just as wonderful and as worthy of study as any other part. Whether one is dealing with its history before man appeared on the scene, the changes that long generations of farmers have brought about, its remarkable structure or the infinite wonder of its microscopic inhabitants, it presents at least as interesting a study as anything else in this wonderful world

of ours. The man who has learnt to see something in the soil will have a better time at farming, even if he makes no more money, than the man who has not.

I hope the student will carry out the experiments given here as well as those given in my earlier *Lessons on Soil*. The analytical methods are put in the Appendix for the convenience of those who want them; it is not intended that all should be carried out by the student but only such (if any) as may be desirable. I have assumed no knowledge of chemistry: all the same the student will need some chemical explanations, but these must be supplied by the teacher. The vexed question of how much pure chemistry is needed for an agricultural course admits of no general answer: the teacher alone can settle the matter for his own case and to him therefore the decision is left.

To my colleague Dr Hutchinson I wish to tender my best thanks for the care he has bestowed on the photographs for the book.

E. J. R.

ROTHAMSTED EXPERIMENTAL STATION,
HARPENDEN.
October 1915.

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PART I

AN ACCOUNT OF THE SOIL

CHAPTER I

WHAT THE PLANT WANTS FROM THE SOIL

It is impossible for anyone to know all about any natural object, however simple it may appear. A wheat plant looks at first sight as if it were an easy thing to study, yet in spite of years of work a chemist would have to confess himself unable to give a complete account of the substances it contains, a botanist would have to admit that much of its structure is unknown to him, and a physiologist would acknowledge that he is unacquainted with a great deal that is fundamentally important to its life-history. And so it is with the soil. Chemists, geologists, bacteriologists and others have all studied it, but those who have done most would be the first to admit that we really know very little about it, and much still remains to be discovered.

The farmer or the gardener is chiefly interested in soil as the place where his plants grow, and this aspect of the soil, its relation to plant growth, is particularly investigated in agricultural laboratories.

Before it can seriously be studied we must first know what the plant wants from the soil: we can then proceed to see how and in what way the soil fulfils these requirements. It is the business of plant physiologists to ascertain what the plant wants, and we must therefore start out with the information they have provided which, however, we must test for ourselves before we finally accept it.

Six conditions or factors are known to be necessary before the plant will make good growth: the soil must supply a suitable amount of: (1) food, (2) water, and (3) air; (4) it must be at a proper temperature; (5) there must be enough of it to afford adequate root room; (6) it must be free from injurious substances or pests. What is exactly a suitable amount cannot be stated beforehand but can only be found out by trying; because different plants, and even different varieties of the same plants, have different requirements. Thus an azalea needs all the six conditions and so does a barley plant, but the suitable amount is very different in the two cases. It is unfortunate that no one has yet discovered any way of finding out the suitable amounts simpler than actual trial because this particular method, though it looks straightforward, is really very cumbersome and liable to give misleading results as we shall see later on.

All these six conditions are wanted and no one of them can take the place of any other. If a plant is dying for lack of water it will not recover by receiving more food or more air. A proper supply of *all* the factors must be maintained, and if any one is insufficient the plant suffers. This proposition looks simple enough but the student must fix it carefully in his

mind because it really lies at the foundation of all our work. It is convenient to use a special name for the lacking condition, the insufficiency of which is preventing the plant from making better growth, and to speak of it as the "limiting factor." Thus

Pot No. 47 55 63

Fig. 1. Tomatoes growing on a light sand with varying food supply. Pot 47, without manure. Pot 55, one dose of manure. Pot 63, two doses of the same manure.

on a dry chalky soil the water supply is often the limiting factor; if more water is got into the soil a bigger crop will be obtained. In the cold summer of 1912 the temperature was on many farms the limiting factor; had the days and nights been hotter the plants would have made more growth. On poor

Plot 3 5 6 7 8

Fig. 2. Effect of increasing dressings of fertilisers on the yield of wheat, Broadbalk, Rothamsted.

Plot 3. No manure.

Plot 5. Manure complete except for one constituent—Nitrogen is omitted.

Plot 6. Complete manure containing 43 lbs. Nitrogen per acre.

Plot 7. Complete manure containing 86 lbs. Nitrogen per acre.

Plot 8. Complete manure containing 129 lbs. Nitrogen per acre.

Pot No. 17 19 21 24

Fig. 3. Tomatoes grown in good soil, all equally manured, but receiving different quantities of water.

Pot 17. No water added.
,, 19. 5 per cent. added, and the moisture then kept constant.
,, 21. 10 per cent. added ,, ,, ,,
,, 24. 12½ per cent. added ,, ,, ,,

Pot No. 47 55 63 72 79

Fig. 4. Tomatoes supplied with increasing doses of manure.

Pot 47. No manure.

Pots 55 to 79. Increasing dressings of manure. This increases the amount of growth up to Pot 72 but it depresses growth in Pot 79 where too much is given. The middle pot, 63, is best for fruit.

soils the food supply is the limiting factor, and addition of more food in the form of manure will increase the crop. The problem of successful management of soil fertility resolves itself into finding out what is the limiting factor and then correcting it as cheaply and completely as possible. This is easy enough on paper but often difficult in practice.

It is a general rule that if any one of the necessary factors is increased in amount there will be an increase in crop growth. This is shown in Fig. 1 illustrating three pots of tomatoes growing in the same soil, sown at the same time and treated alike in every respect except one. The soil is a very light sand; in one pot there has been no addition of plant food; in the second the crop has received a dose of manure, and in the third it has received a larger dose. A similar result is obtained in the field as shown in Fig. 2; the shortest wheat plant is a representative specimen of the crop on the unmanured land; the next plant shows what happens when an almost but not quite complete manure is added; the third shows the marked gain when one dose of complete manure is given; next comes the effect of two doses; and the last shows the effect of three doses. In all cases an increase in the amount of plant food has led to an increase in the crop.

Very similar results are obtained when the water supply is varied. In Fig. 3 are shown tomato plants growing in a good soil, sufficiently and equally manured, and under the same favourable conditions of light, temperature, air, etc. All the conditions, excepting one, are the same for all pots: the water supply only varies. When only little water is given the

growth is poor in spite of the presence of food and the favourable temperature and light conditions; when more water is added there is better growth; finally with adequate water supply growth is really good.

But growth will not go on indefinitely. A limit is reached sooner or later beyond which the plant will not make any more growth no matter how much food or water is given. Indeed it is easy to overstep the limit and give too much so that the crop actually suffers. This has happened in the experiment recorded in Fig. 4. Here, as in Fig. 1, tomatoes are shown growing in soils provided with different amounts of manure. The first and second doses of manure resulted in an increased crop: the third dose caused no further increase: while the fourth actually caused a decrease, the excess of food now acting as an injurious substance. This is well seen also in Pots 27 and 36, Fig. 5 (top row).

The limit reached in any particular instance, however, is not necessarily the best growth that can be obtained. It may be set by the insufficiency of water, of temperature, etc. Fig. 5 shows in the upper part a set of tomato plants supplied with successively increasing amounts of manure and 5 per cent. of water; in the middle a set supplied with the same amounts of manure and 10 per cent. of water; and in the lower part a third set also receiving the same quantities of manure but 12·5 per cent. of water—this being as much as the soil would hold. The limit of growth reached in the first case is clearly due to a deficiency of water, for it is raised considerably when more water is added. But a still further increase in the supply of water does not lead to more growth, the

Pot No. 3 11 20 27 36

5 per cent. water.

Pot No. 5 13 21 30 38

10 per cent. water.

Pot No. 7 15 24 32 39

12½ per cent. water.

Fig. 5. Tomatoes grown in soil receiving successively increasing doses of manure in pots passing from left to right. Pots 3, 5, 7, no manure; Pots 36, 38, 39, ten doses manure.

Top row:	moisture	maintained at	5	per cent.
Middle row:	„	„	10	„
Bottom row:	„	„	12½	„

limit being now set by something else. It is possible that by increasing the temperature or the root room we could get more growth out of this last series, but the process comes to an end before long and the final limit is set by the sheer inability of the plant to grow any bigger. If larger crops are wanted it becomes necessary to try some bigger yielding variety, *i.e.*, some plant that has got more power of growth.

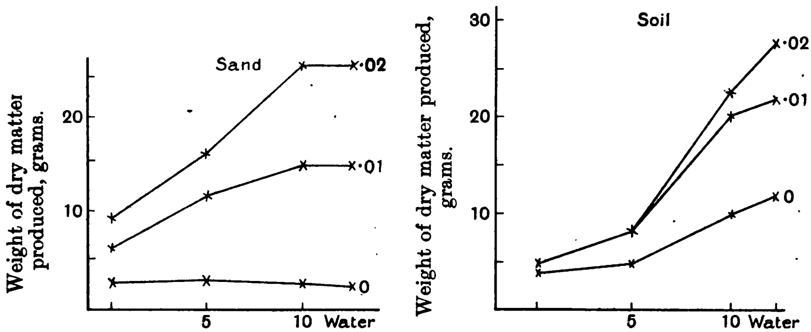

Fig. 6. Curves showing weights of crop produced with varying supplies of water and 0, ·01 and ·02 grams of nitrate of soda per pot.

All these results are shown in the curves of Fig. 6. But there is something more than actual growth. The student who carries out the experiment will observe that some of the plants differ very much in appearance and agricultural or horticultural value even when their weights are not unlike. Between Pots 3 and 7 (Fig. 5), for instance, there are great differences in appearance and habit of growth. Pot 3 (5 per cent. of water and no nitrate) contains sturdy plants capable of great development if transplanted into more favourable conditions, while Pot 7 (12½ per cent. water and no nitrate) contains "leggy" plants that would

never be of any value. Similarly the wetness of the soil affects the root development: in a dry soil there is more root than in a wet one: von Seelhorst showed that barley growing in a soil watered only to half its full water-holding capacity produced twice as much root as when the water was maintained at three-quarters the full capacity. These differences are highly important from the practical point of view but they are much more difficult to investigate than mere changes in weight.

From these and similar experiments we may deduce three general principles of the highest importance in the study of soil fertility:

(1) Six separate soil factors are necessary for the successful growth of the plant: there must be an adequate supply of food, water, air, a suitable temperature, sufficient root room and an absence of harmful substances. If any of these conditions is not complied with the plant fails to grow well: the lacking condition is called the *limiting factor* and it must be supplied before further growth takes place.

(2) By increasing the supply of any of the factors necessary for the plant (food, water, temperature, etc.) an increase in growth is obtained. But a limit is sooner or later reached beyond which further growth will not take place. Additional increases in the food, water supply, temperature, etc. may do positive harm.

(3) When a crop has been increased by improving one of the soil conditions (*e.g.*, the food supply, water supply, etc.) it is always possible that some other factor which sufficed for the original crop is no longer sufficient for the new and larger crop. Thus a limiting factor comes into play and prevents the farmer from

getting as large a return as he should from his outlay. It is therefore necessary in all cases where land has been improved to see that the screwing up of efficiency has extended to all the six soil conditions, and finally to see if some new variety of crop with larger power of growth cannot be obtained that will do even better than the best of the old varieties.

What is plant food?

In a general way the grower knows that he feeds his plants when he gives them stable manure, liquid manure, soot, bone meal and other substances. The list of plant foods is very large, indeed probably larger than that of animal foods. When, however, these foods are examined by the chemist they are found to owe their value to the presence of six substances: nitrogen, phosphorus, potassium, calcium, sodium, and magnesium. These therefore represent the essential constituents of the foods supplied. Closer investigation has shown that in addition sulphur, iron, and probably small quantities of other substances are needed. These eight or nine elements are commonly spoken of as the nutritive elements. They can only be utilised when they are combined in some way, and as a rule it is in the form of soluble salts that they are actually taken up by the plant. Thus the nitrogen is commonly taken in the form of nitrates or ammonium salts; phosphorus in the form of phosphates; potassium, calcium, and magnesium in the salts of these metals. All these substances occur in the soil, and they are often spoken of as plant food.

It must be admitted that the term is not entirely

above criticism, because we do not know that all the substances which enable a plant to grow bigger are really foods in the ordinary sense of the term. Indeed there is physiological evidence to show that they are simply the raw materials out of which the food is made by the plant for its own use. Further, by far the greater part of the material of the plant is derived from water, carbon dioxide, and oxygen, substances which come from the air and do not figure at all in the above list. But the term survives because of its convenience.

In later chapters we shall discuss the effect of the various substances on the plant. For the present it is sufficient to point out that each individual constituent element is subject to the same laws as any of the other soil factors: each must be present to the proper extent, and lack of any one cannot be made good by putting in more of any other. When a soil is deficient in plant food it need not necessarily receive a complete food: often only one or two constituents are required. The discovery of this fact completely revolutionised the practice of manuring and has enabled farmers to maintain and even to increase the efficiency of their soils as crop producers at a minimum of cost. Such partial manuring, however, has obviously to be done intelligently or an insufficiency of something that has been left out may operate as a limiting factor and prevent the crop making proper growth. In order to understand the principles involved it is necessary to make a careful study of the soil and of the different manures in common use.

CHAPTER II

THE COMPOSITION OF THE SOIL

THE reader must often have noticed in walking along a lane after a heavy rainfall, that the water streaming down a bank has washed away the soil in a somewhat uneven manner, leaving behind the grit and small stones but carrying away the rest. In following the course of such a streamlet one observes that at certain points a smooth cake is formed which cracks as soon as it begins to dry, and is much more sticky and clay-like than the original soil. Closer observation shows that the original soil has been separated into various constituents by the running water, the heavier coarser particles being left behind while the finer lighter particles are carried on.

This effect of a flowing stream has suggested a method for analysing soil that has proved extremely valuable and is largely adopted by soil investigators. It consists in allowing a stream of water to flow over the soil and to sort out the particles according to their degree of fineness. One form of the apparatus for doing this, designed by Nöbel, is illustrated in Fig. 7. 25 grams of the soil are put into the smallest of the pear-shaped vessels *A*, and water is run in. As the vessels are of different diameters the water flows through them at different rates, going most rapidly through the narrowest and most slowly through the widest, *D*. When it runs rapidly it carries away the fine material leaving only the coarse: when it

goes more slowly it deposits some of the fine material. Hence after a time the soil put into the apparatus has become sorted out into grades, the coarsest particles only remaining in the smallest vessel *A*, while the other portions of successively finer particles are distributed over the larger vessels *B*, *C*, and *D*, till finally the smallest particles of all get washed out into the large vessel *E*.

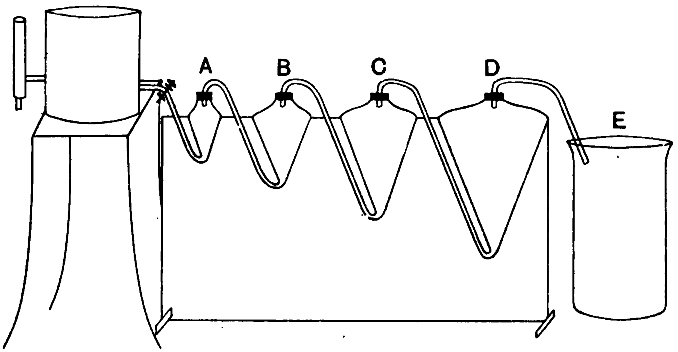

Fig. 7. Nöbel's apparatus for sorting out soil particles.

Instead of allowing the water to flow over the soil the separation may equally well be brought about by allowing soil to fall through water. A simple apparatus devised for the purpose by J. Alan Murray is shown in Fig. 8. A long glass tube about 50 ins. long and one inch wide is fitted by means of a wide piece of rubber tube to a 200 c.c. Erlenmeyer flask with a neck one inch wide containing 5–10 grams of soil. The flask is half-filled with water and vigorously shaken so as to break up the soil, then it is almost completely filled with water and attached to the long tube. The whole apparatus is now filled up with

water and inverted in a vessel of water. Instantly the soil begins to tumble through the water, but some of it falls more quickly than the rest. The large coarse particles reach the bottom of the tube very quickly and form a little layer there, or, if the tube is left open, they can be collected in a small dish. Next come the small but still coarse particles. After these the fine particles begin to come down and at the end the finest of all settle as a light mud.

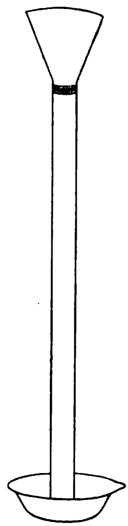

Fig. 8. Murray's apparatus for sorting out soil particles.

More refined methods are in use in analytical laboratories. The lumps of soil are first broken down by a wooden pestle and then by treatment with very dilute acid followed by ammonia. Next the soil is passed through sieves of known dimensions which sort out the particles of a certain size. Finally it is stirred up in a column of water of measured height and allowed to settle for a certain time. The details of the method are given in the Appendix, and the student is advised to carry out an analysis of a soil with which he is familiar. It can be shown mathematically that the speed with which a particle sinks through the column of water is proportional to the square of its radius, hence the method enables us to grade the particles according to their size. Numerous investigations have brought out the remarkable fact that the soil contains many particles as small as $\frac{1}{125000}$ inch in diameter, while the largest particles in the fine earth are only some $\frac{1}{25}$ inch in diameter. Still

more remarkable perhaps is the fact that no natural division usually occurs between the various constituents; the particles merge by imperceptible gradations from the very coarsest to the very finest. It is convenient to make divisions for the purpose of analysis and investigation, but we must not forget that they are entirely arbitrary and have no existence in nature. In this country the following grades are adopted:

	Diameter of particles
Stones	Above 3 mm.
Gravel	Between 3 and 1 mm.
Coarse sand	„ 1 and 0·2 mm.
Fine sand	„ 0·2 and 0·04 mm.
Silt	„ 0·04 and 0·01 mm.
Fine silt	„ 0·01 and 0·002 mm.
Clay	Below 0·002 mm.

The clay on the whole possesses a certain set of properties and the fine silt possesses a different set. Nevertheless one cannot sharply distinguish the clay from the fine silt because a considerable amount of material occurs on the border line, possessing some of the properties of both. Wherever the line is drawn some material gets included with the clay that behaves rather like fine silt, and other material is included with the fine silt that is rather like clay. It is equally impossible to draw a sharp distinction between the silt and the fine silt on the one hand, and the silt and fine sand on the other. Wherever limits were selected they would still be open to criticism, and the groups adopted in this country might no doubt be improved upon. Nevertheless, so many analyses have now been made here by this method that no change would be justifiable

unless some great fundamental advantage would be gained thereby.

The older chemists taught that soil is composed of two earths: sand and clay. It is now known that this view is incorrect. Soil is not composed of two earths: it is formed of vast numbers of particles ranging without any break from the largest to the smallest, and it defies all attempts at being subdivided into any rigid number of constituents. As a matter of convenience five or six groups are distinguished, but we recognise that our grouping is arbitrary.

The material sorted out in the above experiments can be used to discover some of the properties of the various fractions. The coarsest material on examination is found to be hard and gritty, to dry quickly and to separate out readily into individual grains. The finest material, on the other hand, is soft and smooth, it dries slowly and forms a cake which cracks into little flakes that curl up in a curious manner. If one of these flakes is dropped into water it falls to the bottom in one piece, but if it is rubbed between the fingers under water it breaks up into particles so minute that they do not settle but make the water turbid.

The question at once arises: why are the particles so different in size? Why are some so small and others so large? An obvious answer is that the large particles are perpetually breaking up into little ones and that the fine sand represents a sort of half-way stage between gravel and clay. This, however, is not entirely correct. The sand is made of different material from the clay, and we can soon see why it has not been reduced to so fine a state. Put into one test-tube 1 gram of the

sand and into another 1 gram of the clay: add 20 c.c. of strong hydrochloric acid to each, plunge the test-tubes into a beaker of boiling water and leave for an hour. Hydrochloric acid is a potent solvent, and dissolves material that is not highly resistant. At the end of an hour the clay is seen to yield a markedly coloured solution while the sand only gives a slightly yellow solution: filter these and add ammonia to each until the liquid turns red litmus blue: the solution from the sand gives only a slight precipitate while that from the clay gives a much denser one. Thus we conclude that sand is much more resistant to the attack of acids than clay. The same result is obtained when the sand and the clay are exposed to the weathering agencies: the sand resists more than the clay and therefore is less completely broken down. Silt comes in between sand and clay in point of resistance.

We must now proceed a stage further and try to discover how the particles got there and what their history has been.

The origin of the soil particles

The soil particles have originally been derived from the rocks, and their present state is the outcome partly of the nature of the rock from which they arose and partly of the circumstances through which they have passed. The original rock gradually crumbled by alternate warming and cooling and by the action of water or ice; the particles formed were carried by wind, by streams, rivers or glaciers for a greater or less distance and ultimately found their way to the sea and there they were deposited. In course of time

the pressure of the great accumulation of material caused some of it to be converted again into rock and, when the sea-floor was uplifted to form dry land, this new rock thus exposed went through the same processes of disintegration, and again the particles were exposed to air, to water and to ice. Sometimes they remained where they were, or were carried only short distances: sometimes they were carried away a great distance. In many districts, as in Central and Eastern Europe, parts of Asia and of the Middle West of the United States (*e.g.* in Nebraska), wind was the transporting agent and the soils thus formed, known as loess soils, are remarkable for the narrow range of variation in size of their particles, the wind only being able to carry particles of certain dimensions. Over much of England north of the Thames, and the northern parts of the United States, glaciers carried the particles to their present position, grinding them sometimes almost to impalpable powder. Elsewhere flowing water was the transporting agent. From the moment the original rock solidified right down to the present day the particles have been subjected to all those influences of rain, frost, heat and water that are collectively summed up in the term climate. The particles as we find them to-day are largely the result of the conditions through which they have passed. The past history of the soil has had an enormous effect on its present character, indeed in many cases the properties of the soil were largely settled in geological ages far remote from our own. Thus the red Triassic soils formed mainly under continental conditions with much wind-drifted material are quite distinct in character from the poor

clays of the coal measures that preceded them or the grey soils of the succeeding Lias: all these differ considerably from the Oxford Clays and these in turn from the Weald Clays.

The rock from which particles originally sprang has also determined the character of the soil. One of the commonest mineral substances on the earth is silica, the chief constituent of quartz, flint, and sand. In these forms it is so hard that it can only be powdered with difficulty, it is also only very slightly soluble in water. The sands on the sea-shore afford sufficient illustration of its properties: in spite of the persistent hammering of the waves, the washing of the sea and the rain, and the exposure to all sorts of weather, it undergoes no perceptible change in any period within the memory of an individual; the sand may get carried away but it does not appreciably dissolve or break down under the influence of these agencies. The immediate ancestor of sand is commonly a sandstone rock which is itself composed of grains of sand united by some kind of cementing material. When the rock was exposed to the action of the weather the cement got washed away and then the whole structure fell to pieces, grains of sand having little or no power of holding together by themselves.

This great resistance of sand to the action of water and weather is its most striking property and gives rise to consequences of very great agricultural importance. It gives up little or nothing to plants and hence is in no sense a plant food: indeed plants quickly starve in it. Its particles show very little tendency to break down and remain for the most part rather large in size, varying, as we have seen, from

1 mm. ($\frac{1}{25}$ in.) to 0·04 mm. ($\frac{1}{625}$ in.) in diameter. Even the edges do not easily wear away, and the particles remain irregular in outline. Their large size and irregular shape prevent them from packing very closely, and large pore-spaces are left in between. Consequently air gets in very easily, water rapidly flows through, and the sand speedily dries, at any rate near the surface.

Another very important group of mineral constituents also contains silica, but in a state of combination with iron, aluminium, calcium, magnesium, sodium, potassium, etc., forming substances known as silicates. Some of these, like sand, are very resistant to the action of water and weather so that they remain as relatively coarse particles and behave agriculturally like sand. Others, however, are more easily acted upon with two important results. Instead of being inert, like sand, they are reactive, *i.e.*, they will act upon various substances that may be brought in contact with them, such as superphosphate, sulphate of potash, etc. The action of water and weather not only rounds off any edges they may have possessed, but reduces them so much in size that they become extraordinarily small and form the particles which tail off from 0·002 mm. ($\frac{1}{125000}$ inch) in diameter to much smaller dimensions. Substances of this nature are the essential constituents of clay, indeed the agricultural chemist regards them as the true clay, any larger inert particles being simply admixtures.

Clay is remarkable in that it can exist in two states; one being sticky and the other crumbly or flocculated. A number of other substances are known that do the same and they are included in the class

known as colloids—a word that means "like glue." Clay is such a dominating substance that it impresses its properties on the soil to a considerable extent, hence when the clay is in the sticky state the whole soil becomes sticky, and conversely, when the clay is in the crumbly state the whole soil becomes crumbly.

Practical men have long since learned that the crumbly state is good for plants while the sticky state is not, and they have also discovered how to change one into the other. Addition of lime, chalk or limestone causes the change to take place rapidly: organic matter (such as farmyard manure, or green crops ploughed in), frost, and good cultivation also have the same effect. On the other hand alkaline manures such as liquid manure, and manures like nitrate of soda that leave an alkaline residue in the soil, tend to change the crumbly back into the sticky state, and if much clay is present they have a bad effect on the condition of the soil.

These changes are readily demonstrated by experiment. Stir up some clay in rain or distilled water, pour off the turbid liquid and divide it into three equal parts. To one add 5 to 10 c.c. of lime water: to another the same quantity of dilute ammonia solution: leave the third alone. Flocculation is seen to take place rapidly under the influence of lime; the untreated portion settles much more slowly; ammonia almost entirely prevents settling. The effect on drainage can be shown by putting a layer of clay supported on a perforated disk into each of three funnels: sprinkle lime on one; pour 10 c.c. of dilute ammonia solution on to another. Then pour water on to all three so that it stands at the same height in each funnel:

leave for a time. Percolation begins first on the limed clay: next on the untreated clay; but proceeds only slowly if at all on the clay treated with ammonia.

More careful experiments have shown that *chemically pure* lime does not flocculate clay but behaves like ammonia: flocculation only goes on in presence of a little carbon dioxide which, however, is always present in the soil.

Silts. Between the inert sand particles and the reactive clay particles there come a number of others of intermediate grade differing somewhat from either. As they are smaller than sand they pack together with smaller pore-spaces which retard the movements both of air and water. Further, they show more tendency to stick together. Whether or not they have distinct chemical properties is not clear, nor is it always known precisely from what minerals they arose. But they constitute a large part of the soil, and have so characteristic an agricultural effect that they are called by the special name of silt. It is usual in this country to distinguish two grades: silt, the particles of which vary in diameter between 0·04 and 0·01 mm., and fine silt, the particles of which range between 0·01 and 0·002 mm. in diameter, but, as already pointed out, the distinction is rather one of convenience than of reality.

The fine silt differs in one important respect from clay: it is not flocculated and rendered less sticky by the addition of lime, or by frost or cultivation. Thus if a soil contains sufficient fine silt its stickiness and heaviness cannot usually be remedied by liming, or indeed by any method known at present. Such soils occur on the Boulder Clays, the Lower Wealden

Beds in Sussex, and elsewhere, and they are always a source of trouble: a good instance is seen at the Leeds University Farm at Garforth. The simplest plan is to leave them in grass, but even this device is not entirely satisfactory.

There is another type of rock which in places has played a great part in the formation of soil. Chalk covers a large area of the eastern half of England, including portions of the counties eastwards of the line joining Lincolnshire and Wiltshire. Chalk is a substance of perfectly definite character entirely distinct either from silica or silicates. It dissolves somewhat in water, and still more readily in water containing carbon dioxide, a gas breathed out by ourselves, by animals and by plants. As all soil water contains some of this gas the chalk readily dissolves, so much so that in many districts, especially in chalk districts, the spring and well waters become very rich in this constituent and it gets deposited on boiling and forms a fur in boilers, kettles, etc.; sometimes it even deposits on standing, forming a sediment in the vessel or a crust on any subject lying in the water. Chalk is decomposed by strong heat giving off carbon dioxide gas and leaving lime behind: this is the change that goes on in a lime kiln. Careful studies of the decomposition have proved that 100 parts by weight of pure chalk, after the removal of all impurities, invariably give rise to 56 parts by weight of lime and 44 parts by weight of carbon dioxide. This relationship is very important for it shows how chalk is built up: it may be expressed thus:

Chalk or calcium carbonate	= lime or calcium oxide	+ carbon dioxide
100	56	44 parts by weight.

When chalk is shaken with rain water a little dissolves. But if the mixture is treated with carbon dioxide a much larger quantity dissolves. This is easily shown by the following experiment: Take some fresh rain-water and divide into two lots of 100 c.c. each: to each add 1 gram of finely powdered quarry or precipitated chalk. Shake one lot occasionally: blow your breath (which contains carbon dioxide) through the other at intervals during five minutes. Then leave for a little time to settle. Pour each liquid through a separate filter, measure 50 c.c. of each into beakers and evaporate on the water-bath. Although the filtered liquid was perfectly clear it is seen to leave a distinct residue after the experiment showing that some of the chalk has been dissolved: a larger quantity of residue is found in the water through which carbon dioxide was blown.

A much quicker way of dissolving calcium carbonate, and one largely used in laboratories, is to treat it with a strong acid, when decomposition takes place and carbon dioxide is evolved. 100 parts of calcium carbonate give rise to 44 parts of carbon dioxide just as it did on heating, but the remainder, instead of appearing as calcium oxide, appears as a salt. Thus if sulphuric acid is used the reaction is:

Calcium carbonate + sulphuric acid = calcium sulphate + carbon dioxide
100 44 parts by weight.

This reaction is so important that it must be studied in an actual experiment: Weigh out 0·5 gram of calcium carbonate[1] in a 50 c.c. conical flask, put in

[1] Whiting is a sufficiently pure form. If it is not convenient to weigh the gas as described above the volume can be measured and the weight calculated in the usual way. 1 c.c. of CO_2 at 0° C. and 760 mm. pressure weighs ·002 gram.

a small tube of strong hydrochloric acid, cover the calcium carbonate with water, and then stop the flask with a cork bored with two holes, one to admit a tube passing to the bottom of the flask, the other to hold a tube that just dips into the flask and then connects with a wide tube holding calcium chloride, a powerful agent for absorbing water vapour (Fig. 9). Carefully wipe the whole apparatus with a soft duster,

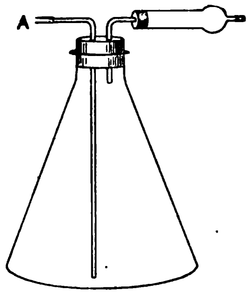

Fig. 9. Apparatus for determining carbon dioxide in chalk.

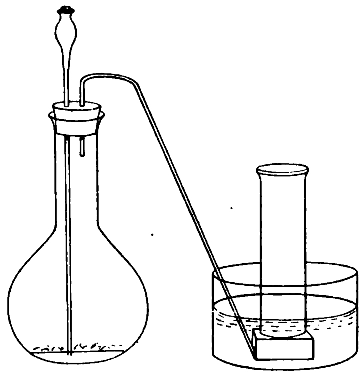

Fig. 10. Collection of carbon dioxide from a soil rich in chalk.

leave it standing for a time in the balance case and then weigh. Next tilt the acid gently on to the calcium carbonate and see how the carbon dioxide is given off. After effervescence ceases blow air gently through the tube *A* to displace the carbon dioxide and then weigh again. The loss of weight represents the carbon dioxide.

Next treat some soil with sulphuric acid. If there is vigorous effervescence you can proceed to study the gas evolved. Put some soil into a 250 c.c. flask fitted

with a thistle funnel and delivery tube: pour sulphuric acid—1 part of acid to 1 of water—on to the soil and collect the gas over the water (Fig. 10). Put a lighted taper to the jar: the gas will neither burn nor will it allow the taper to burn. Pour in some clear lime water: a dense milkiness is produced. Collect another jar of the gas and stand it over caustic soda. The gas is rapidly absorbed and the soda rises in the jar. A third jar can be used to demonstrate the heaviness of the gas as compared with air: pour the gas into an empty jar containing some clear lime water: a milkiness is produced. Now all these properties are identical with those of the gas obtained from chalk treated in the same manner, and we can therefore conclude that the gas evolved is carbon dioxide and further that a carbonate is present in the soil. We cannot say what carbonate, because as a matter of fact all carbonates would decompose under the same circumstances to give carbon dioxide. There is evidence to show that calcium carbonate is the chief one in the soil and it has become customary to speak as if this were the only carbonate, although it is known that others also occur. Thus in forming estimates of the amount of carbonate in the soil it is usual to determine the amount of carbon dioxide evolved and then express this in terms of calcium carbonate.

The experiment made with the calcium carbonate (Fig. 9) should now be repeated with soil. The precise amount to be used depends on the amount of effervescence with the acid: if this is vigorous 10 to 20 grams may be sufficient: if not 25 grams may be needed, while in many cases the method may break

down altogether and another has to be adopted. If there is only slight effervescence it is unlikely that the soil contains more than 0·5 per cent. of carbonates, while many soils contain less.

The calcium carbonate in the soil arises from several sources. The huge masses of chalk represent the remains of minute sea animals, as may be seen by examining some of it under a microscope. The chalk has often been distributed to other soils, sometimes by flowing water and sometimes by glaciers as in the chalky boulder clay of the eastern counties. A second mode of origin of calcium carbonate is from the weathering of rocks, and a third from the decomposition of plant and animal remains. A good deal of chalk, however, has been added to the soil by farmers in the past: some of the fields in Hertfordshire still contain as much as 1 or 2 per cent. put on as top dressings 50 years or more ago.

The constituents dealt with in the preceding paragraphs—the various sands, silts, clay and the chalk—compose almost the whole of the mineral part of the soil. But although the balance is only very small in amount it is of very great importance to the plant, for it contains an essential article of plant food—calcium phosphate. This substance arose in the first instance from the rocks, but often the material in our soils has already done duty in past ages, and has helped to build up the skeleton of some organism, on the death of which it has again returned to the soil to do duty once more. It is readily detected by heating 20 grams of soil with concentrated hydrochloric acid on a water-bath for an hour, filtering, and adding to the filtrate a solution of ammonium

molybdate[1]. A yellow precipitate comes down containing the phosphoric acid extracted by the hydrochloric acid.

The red or yellow colour of the solution is due in part to the iron present. On neutralising with ammonia a dense red precipitate containing iron and aluminium oxides comes down and can be filtered off: the presence of iron can then be confirmed by the beautiful blue precipitate obtained when the red material is dissolved in a little hydrochloric acid and treated with potassium ferrocyanide solution, or by the very deep red colour obtained when some of the hydrochloric acid solution is almost neutralised with ammonia and then treated with potassium sulphocyanide solution.

Another constituent of the hydrochloric acid extract of the soil is potassium which occurred in the complex silicates of the soil. Unfortunately there is no very simple way of demonstrating its presence, but a method for laboratory use is given on p. 196. Both phosphorus and potassium salts are essential plant foods and among the most important constituents of the soil from the farmer's point of view. Yet they do not form any very great proportion of the whole and even in a fertile soil there is often not more than three or four lbs. of either in a ton of soil whilst the amount that plants can get hold of may only be a few ounces. The plant, however, does not want a great deal; one ton of mangolds only contains some 10 lbs. of potassium and 1½ lbs. of phosphorus[2] so that the

[1] See Appendix, p. 196.

[2] In accordance with British custom these amounts are stated as the oxides, K_2O and P_2O_5.

quantities present are not as inadequate as they appear.

We have now come to an end of the important mineral constituents of the soil. When such a soil is supplied with water, is properly aerated, and receives a sufficient amount of heat from the sun, it speedily becomes the abode of many plants and animals. As these die their remains mingle with the soil, and so a fresh constituent appears, known as organic matter, which has the distinguishing characteristic that it got there through the agency of living organisms and has the chemical distinction of being easily and completely burnt away. The presence of this organic matter is easily shown by heating some soil on a tin lid or in a crucible; the soil blackens or chars, then little sparkles of fire can be seen, and finally all the combustible part smoulders away leaving only the mineral constituents. The organic matter is so important that it must be dealt with in a separate chapter by itself.

It has become customary to talk of the "nitrogen," "phosphoric acid," "potash," "lime," etc. in the soil, but the student must at the outset realise that these do not exist *as such* in the soil. The nitrogen meant is not nitrogen as it occurs in the air, and which is better spoken of as *gaseous* nitrogen: it is nitrogen combined with other substances. "Phosphoric acid" does not occur in the soil, but only its compounds, the phosphates; "potash" and "lime" do not occur, but only potassium and calcium salts. These distinctions must be clearly grasped: failure to understand them will result in considerable confusion later on.

The mineral and organic constituents, however, do not form the whole of the soil mass, but only one-half to two-thirds of it; the remainder is filled with air and water which are of vital importance to the roots of the plants and to the soil organisms. The air resembles ordinary atmospheric air in composition, but it contains more carbon dioxide and more water vapour:

	Oxygen per cent. by volume	Nitrogen per cent. by volume	Carbon dioxide per cent. by volume
Atmospheric air	20·95	79·02	0·03
Soil air, arable	20·5	79·2	0·3
Soil air, pasture	18·2	80·2	1·6

When the soil becomes waterlogged, however, the percentage of oxygen may fall very considerably so that insufficient is left for the organisms to carry on their usual functions. Undesirable changes may then set in. The presence of more carbon dioxide in the soil air than in the atmosphere is readily demonstrated by driving a ½ inch gas pipe to a depth of 6 inches in the soil and connecting it with a test-tube containing 20 c.c. of baryta water and attached to an aspirator. A similar tube also containing 20 c.c. of baryta water but open to the air is attached to the same aspirator. Set the aspirator working and arrange the connections so that bubbles pass at the same rate through the two lots of baryta water. The one connected with the soil speedily becomes turbid, indicating the presence of carbon dioxide, the other, open to the air, however, only shows turbidity later on (Fig. 11).

The water is held by physical forces in the pores and the amount present depends on the rainfall, the evaporation and the drainage. In the Rothamsted

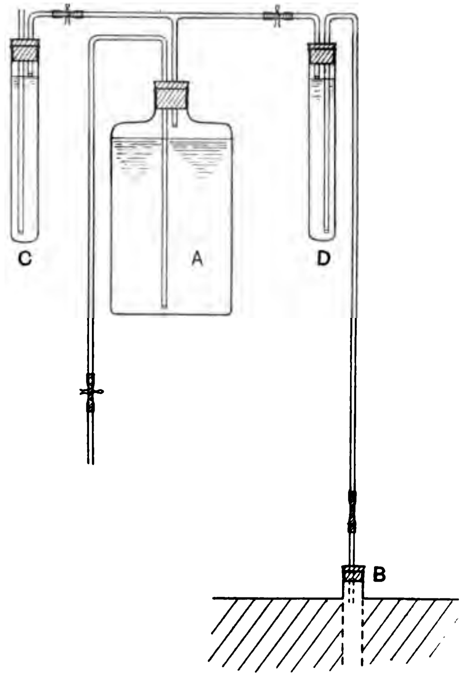

Fig. 11. Apparatus for demonstrating the presence of CO_2 in soil air.
A. Aspirator. B. ½″ gas pipe driven into soil.
C. Tube of baryta water open to air.
D. ,, ,, connected to soil.

measurements the sandy soils were generally found to contain about 9 per cent., the loams about 12 per cent., and the clays about 27 per cent. by weight; a better idea, however, is furnished by taking the

proportions by volume, which vary from 20 to 40 per cent. The following are the figures for some of the Rothamsted soils:

	Vol. occupied in natural state by		Volume of water		Volume of air	
	Solid matter	Air and water (pore-space)	In normal moist state	After period of drought	In normal moist state	After period of drought
Poor heavy loam	66	34	23	17	11	17
Heavily dunged arable	62	38	30	20	8	18
,, pasture soil	53	47	40	22	7	25

The water is not pure but contains various salts in solution, the most important of which are nitrates and bicarbonates (p. 61).

The subsoil. The lower portion of the soil differs so much from the surface layer that it receives a separate name and is called the subsoil. The difference lies in the fact that neither plant nor animal life has been able to exert any great effect, so that the subsoil contains very little more than the original mineral material. It contains less organic matter than the surface soil, and in consequence it possesses less nutrient plant material and has not the satisfactory physical properties conferred thereby. Usually also it contains more clay and this is present in the sticky rather than the crumbly form. Both causes combine to render the subsoil less tractable than the surface soil, and on heavy soils it may become very bad indeed so that it must on no account be brought to the surface. Indeed many acres of land have been ruined by deep steam ploughing which has buried the surface soil

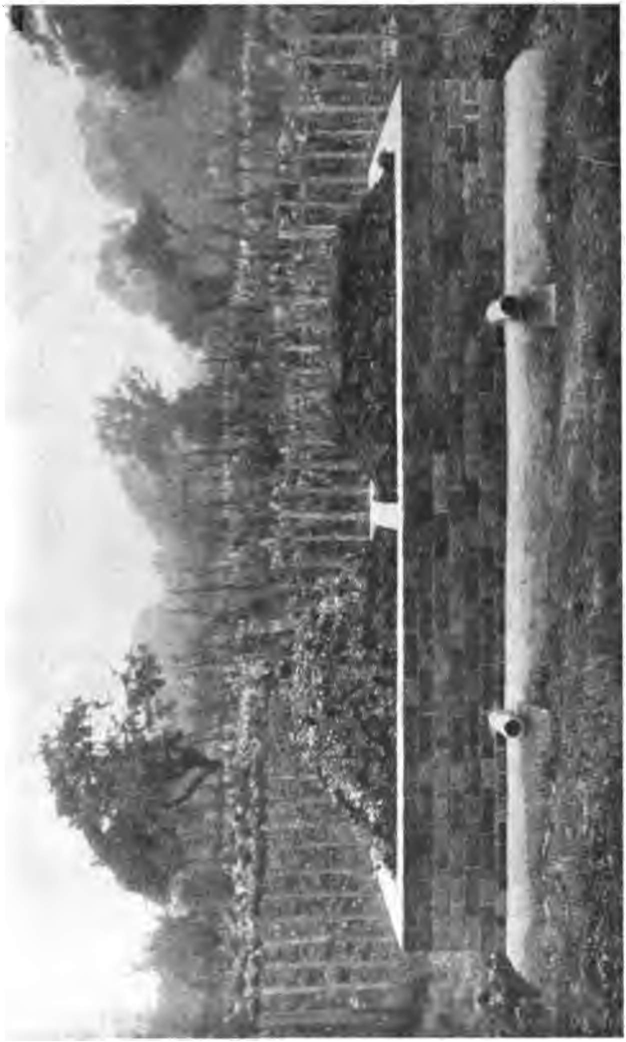

Fig. 12. Brick chambers filled with subsoil the properties of which are being studied. They are heaped up now so as to allow for the settlement that will take place in winter (Rothamsted).

and only left the plants with a sticky unkindly subsoil. An advantage of the one-way or turn-wrest plough is that it does not, like the ordinary plough, leave furrows of barren subsoil throughout the field between each of the lands.

The following experiment has been started at Rothamsted and might advantageously be tried elsewhere. Select some suitable site in the experimental field or garden and construct therein two brick chambers each 20 inches deep, and 7 ft. square with cement floor and lining, making a way out for drainage-water (Fig. 12). Fill both with subsoil obtained during excavations for a building or dug specially. Leave one entirely alone and observe the changes it undergoes: sow the other with crops and observe their manner of growth.

CHAPTER III

THE ORGANIC MATTER OF THE SOIL AND THE CHANGES IT UNDERGOES

THE organic matter of the soil represents, as we have seen, the remains of previous generations of plants and animals and can roughly be sorted out into two divisions according to age: some of it is as old as the soil, having got deposited along with the mineral particles when the soil was first made; some of it is newer, representing the residues of recently living plants. It is not known whether the original organic matter has any particular effect on the soil, but one generally supposes that it has not. Its

properties have been studied by examination of the subsoil at a depth below the range of the surface vegetation.

The more recent material is of supreme importance to the soil. It is subdivided into (*a*) the newest of all, the undecomposed roots or stubble which still retain some of the structure of the plant; and (*b*) the partly decomposed material, dark brown or black in colour, which has fallen entirely to powder and become completely intermingled with the soil; this part is commonly called "humus." The undecomposed part serves two purposes: it is the source from which the humus is derived, and it keeps the soil open and porous, maintaining passages through which water can drain away and air can enter, and preventing the mineral particles from settling down too compactly. In glasshouse practice it is always desirable to keep up the supply and this is done by mixing good fibrous turf in the borders (*e.g.*, cucumber borders) so that the soil shall always remain open and aerated in spite of the constant heavy watering. After a time the fibrous roots disappear and then the soil is much more likely to become sodden, covered with green growths, and "sour," than it was while the fibre lasted. In outdoor horticultural work it is equally an advantage to have sufficient undecomposed or fibrous material to keep the soil open, and afford what the gardener calls a proper root run. On heavy farm soils, also, undecomposed material, such as stubble, straw, long manure, is very helpful for the same reason. On the other hand this material is a disadvantage on light soils because these are already open enough especially in dry seasons. Any fibrous or undecomposed

plant material or manure containing long straw or peat moss is therefore added in autumn so that it may have a good chance of being broken up before the summer droughts come on. On many good light-land farms, indeed, the use of these materials is reduced to a minimum by a method that will be discussed later (p. 105).

This fibrous material contains many of the chemical substances that occur in the plant: among them are protein, cellulose, and waxes. The decompositions that go on in the soil are not known in full detail, but it has been found that the protein breaks down to form ammonia and other substances, some of which, along with the cellulose, give rise to the black mixture humus; carbon dioxide is also given off during the process. There must be many products formed during these decompositions, but very little is known of them with certainty. The waxes only disappear slowly; they tend to accumulate on soils like old garden soils to which much plant matter is added, and they are probably partly responsible for the curious difficulty in wetting these soils when once dry; drops of water tend to stand on the surface and not to soak in.

The mixture known as humus plays a specially important part in soil productiveness. In days gone by humus was regarded as a distinct chemical group and was subdivided into humic acid, ulmic acid, crenic acid, apocrenic acid, etc., but it is now known that these substances are only imaginary; we shall therefore not concern ourselves with them. Humus is a mixture which is not yet satisfactorily resolved into its component parts.

Some of it can be extracted from the soil by means of dilute alkalis, by the following method. Shake 100 grams of soil with 500 c.c. of 5 per cent. hydrochloric acid, allow to settle, pour off through a filter, and wash with water. Then transfer the soil to a bottle, add 500 c.c. of 5 per cent. caustic soda solution, shake, and leave for some hours lying on its side so that as large a surface as possible is exposed to the alkali: shake periodically. Before long the alkali becomes dark coloured. Again allow to settle and syphon off, or, if you can, filter on the Buchner funnel by aid of the pump: this is rather a slow process. To the clear dark coloured filtrate add some strong hydrochloric acid drop by drop till the liquid is just acid. A dark brown precipitate is thrown down containing much of the organic matter. Some, however, still remains in solution: a part of this can be brought down by exactly neutralising with caustic soda, but the rest is only recovered by evaporation. It is sufficient, however, to examine the precipitate. On drying, this shrinks very much to little lumps almost black in colour which readily burn and leave behind a little red ash. Its composition varies considerably, but after it is thoroughly dried in a steam oven it usually contains about 50–57 per cent. of carbon, 35 per cent. of oxygen, and 3–8 per cent. of nitrogen.

The soil which has thus been treated still contains more of the soluble material, and several successive extractions have to be made with alkali before anything like exhaustion appears; even then soluble material still continues to come out although the solution is no longer dark coloured. But even after

numerous extractions a considerable amount of the organic matter—often about one-half of the original quantity—remains in the soil. Some of this is capable of being transformed into soluble substances by heat: thus if a fresh portion of the soil is heated by steam at 100° C. for an hour and then submitted to the extraction processes already described, a considerably larger amount of material dissolves out in the alkali than before.

The chemical nature of these various substances is under investigation at the Bureau of Soils, Washington, and at Rothamsted. For our present purpose it would be premature to discuss the results so far obtained, and we must confine ourselves to another highly important set of properties: the physical effects of "humus." These will be taken in detail in Chapter VI; they fall under three headings:

1. The organic matter imparts a black colour to the soil unless there happens to be a good deal of chalk present, when the white colour persists. It is a well-known physical law that a black substance absorbs more heat than a white one placed under similar conditions, hence the dark colour facilitates the warming of the soil in spring.

2. The organic matter greatly increases the capacity of the soil for holding water. A soil rich in organic matter is throughout the summer and autumn distinctly moister than a soil poor in organic matter (p. 158).

3. Organic matter facilitates the production of a fine tilth and a good seed bed, and it renders cultivation more easy.

Soils well supplied with organic matter are therefore

very valuable to the agriculturist both by reason of the large amount of nitrogenous substances they contain and also because of the ease with which they can be worked. Examples occur in the fen districts in this country, in the prairies of Western Canada, the black earth or Tchernozem of Russia and elsewhere. Wherever they occur these black soils are promptly taken up for cultivation.

There is, however, another type of organic matter which is less widely distributed and much less useful. Peat is organic matter but it is not sufficiently decomposed to be of much value, and peaty soils are not in high agricultural repute. Intermediate between peat and fen comes another type found in the carr soils, which can be made distinctly useful by dressings of lime. Owing to the great importance of the organic matter chemists have made many attempts to determine just how much is present in the soil. Advantage is taken of the fact that organic matter burns away while mineral matter does not: hence some of the soil is burnt, and the loss of weight is measured (p. 194). This method is simple, but unfortunately it is not quite sound for some of the mineral matter undergoes changes on heating accompanied by alterations in weight. Nor does the method discriminate between the undecomposed and the decomposed material which as we have seen behave very differently in the soil. In some laboratories (*e.g.*, at Rothamsted) the larger fragments of undecomposed material are removed by sifting and blowing, and estimated separately. But more usually the whole of the material is estimated together.

Another method of discovering how much organic

matter is present in the soil is to determine the percentage of nitrogen (p. 194). This is important because it gives an indication of the nitrogen reserves in the soil but again it tells us nothing about the state in which these exist and whether they are useful or not. Table I gives typical examples and shows that there is no very clear connection between the productiveness of the soil and the percentage of nitrogen or the loss of organic matter.

TABLE I. *Percentage of nitrogen and organic matter in typical soils and subsoils*

	Fertile arable soils			
Surface Soils				
Loss on ignition	4·65	6·58	3·70	4·65
Nitrogen	·120	·220	·133	·141
Subsoil				
Loss on ignition	3·00	4·94	2·81	3·29
Nitrogen	·078	·139	·081	·097

	Poor arable soils				Barren wastes		
Surface Soils							
Loss on ignition	4·13	6·23	3·60	5·14	5·94	7·00	5·81
Nitrogen	·128	·143	·182	·152	·130	·195	·167
Subsoil							
Loss on ignition	3·74	5·50	2·58	4·14			2·70
Nitrogen	·112	·104	·061	·096			·058

Nevertheless the results are of much value to the agricultural chemist in investigating soil fertility problems.

We must now turn to the changes undergone by the organic matter. During the process of cultivation the organic matter becomes oxidised and some of it

disappears as gas; it thus suffers much more rapid changes than the mineral particles. Illustrations can be seen in parts of North America where the original prairie soil was fairly rich in organic matter but after some years of wheat cultivation it has lost much of its stock. In Minnesota Snyder found that an amount containing 50 per cent. of the nitrogen was lost in twenty years' cultivation: in Saskatchewan Shutt observed a loss of an amount containing 30 per cent. of the nitrogen after a similar period. With the organic matter is lost also the advantages it conferred: the soil becomes impoverished, and, if much clay is present, it becomes difficult and expensive to cultivate. Hence such soils tend to be thrown out of cultivation and to become derelict. Similar losses occur in market gardens and wherever large dressings of farmyard manure are applied: they necessitate the use of more manure than is really needed by the plant and they add to the expense of production.

A closer analysis of the loss shows that the carbon of the organic matter goes off as carbon dioxide and that some at any rate of the nitrogen is changed to ammonia, but it is not certain that all goes in this form, and there is evidence that some is lost as gaseous nitrogen. The question is under investigation at Rothamsted; it is of enormous agricultural importance because of the seriousness of the loss on rich soils and the necessity for reducing all wastage nowadays: it is discussed more fully in Chapter VI.

The ammonia remaining in the soil is at once seized upon by certain soil bacteria, the Nitrosomonas, and converted into a nitrite, and this is taken by another group of organisms, the Nitrobacter, and

converted into nitrate; the process is called nitrification. Thus the ammonia actually appears as nitrate which is readily found in the soil by the simple test given in the Appendix (p. 195). The amount of nitrate is commonly stated as so many parts of nitrogen per million parts of soil; they can be expressed as parts of nitrate of soda by multiplying by 6, or they can be converted into lbs. per acre in the top 9 inches by multiplying by $2\frac{1}{2}$; the results are not quite accurate but suffice for purposes of comparison.

The following amounts of nitrate were commonly found in the author's investigations of various soils:

	Expressed as nitrogen			Expressed as nitrate of soda
	Parts per million 0–9″	Parts per million 9–18″	Lbs. per acre 0–18″	Lbs. per acre 0–18″
Sand	5	4	25	150
Loam	10	8	46	276
Clay	10	6	38	228

Nitrates do not accumulate to any great extent in the soil in our climate, and it is very unusual to find more than 24 parts per million or 120 lbs. per acre (expressed as nitrogen) in the top 18 inches. As soon as these high values are reached further production ceases. It sometimes happens in dry regions that higher amounts are present, but it is usually supposed that they got there by evaporation of water which has soaked in from somewhere else, concentrating the nitrates from a wide area over a particular spot[1].

[1] Dr Headden rejects this explanation for the Colorado soils, and considers that nitrate formation continues *in situ* even after relatively high quantities are attained.

Under our climatic conditions the nitrates do not get the opportunity of persisting long but are either washed out by rain or taken up by plants. Once the stock is reduced a further quantity begins to be formed and so far no limit has been reached to the amount of nitrate a soil can be made to yield. One of the Rothamsted plots which has been cropped with wheat every year since 1843 and has had no manure since 1839 still goes on yielding nitrate and in September 1913 contained nearly 35 lbs. of nitrogen as nitrate, equivalent to 210 lbs. of nitrate of soda in the top 18 inches of soil per acre. Another piece of land is kept bare of all vegetation and is undermined in such a way that the whole of the drainage-water can be collected for analysis. Ever since 1872 when the experiment began the land has yielded a large supply of nitrate, the amount being equivalent to 300 lbs. of nitrate of soda per acre every year for the first 20 or 30 years, and to some 200 lbs. in more recent years.

A further change goes on in certain circumstances. When all air is excluded from the soil by flooding it for a long time with water the nitrates are liable to decompose to form nitrites and subsequently gaseous nitrogen. This change, known as denitrification, only goes on slowly in cold weather and probably is of rare occurrence under British agricultural conditions where land would only be waterlogged in winter, if at all. But it seems to go on in the wet rice fields of the East and in these circumstances nitrates are not used as manure.

All these changes result in loss of nitrogen: fortunately there are others that bring about gains,

chief among them being the fixation of gaseous nitrogen by the organisms in the root nodules of leguminous plants. Some also is fixed by certain free living bacteria called Azotobacter. These require considerable quantities of decaying plant residues as a source of energy: for the process is not one that will continue by itself once it is started like the burning of a bonfire, but rather it resembles hauling a load up a hill and requires the continuous application of energy. The fixation through the root nodules proceeds vigorously during the growth of clover, trifolium, lucerne, sainfoin, vetches, etc., and these crops therefore enrich the soil considerably. Both processes take place in land laid down to grass. The gain does not go on indefinitely: after a time it is counterbalanced by losses; but the net result is that grass land contains considerably more nitrogen than arable land. The nitrogen comes *from the atmosphere*, and thus represents an absolute gain to the stock in the soil. The following simple rule should be remembered by the student: land in sod gains *nitrogen*, land in fallow gains *nitrate*. The gain in nitrogen is absolute, but the gain in nitrate is not, it only represents a change of one form of soil nitrogen into another. When the grass land is ploughed up the gain in nitrogen ceases, and the gain in nitrate begins; sufficient may be produced to yield corn crops so heavy as to justify the ploughing up of pasture which is not of first rate grazing quality. In such cases a root crop is usually taken first so as to give an opportunity of exterminating wire-worms and other soil pests which accumulate under grass and might seriously damage young corn.

The whole chain of processes we have been

describing is of the greatest possible importance to soil fertility because it consists in the conversion of the undecomposed plant residues, which are of little value to the soil except to open it up, into valuable humus material and plant food. The process has therefore to be encouraged by every means in the cultivator's power. It is mainly brought about by living agencies; earthworms play a preliminary part by dragging the materials into the soil and effecting a proper admixture: moulds and bacteria are the important decomposing agents. Fortunately all these organisms require substantially the same soil conditions as plants: thus they need air, water, proper temperature, and food, absence of injurious substances, presence of chalk, etc. The soil population is, however, very complex and the organisms are not all equally useful; there is indeed evidence that some are distinctly detrimental. Hitherto no method of discrimination has been adopted and all organisms good and bad have been allowed to grow in the soil without any intentional interference: methods are now being worked out in horticultural practice for controlling the soil population so as to encourage the useful forms and repress the others. These methods are based on the fact that the useful forms are less easy to kill than the others, and therefore if the soil is heated, treated with mild poisons, dried by the sun, or frozen for long periods during the winter, the survivors are on the whole more useful to the cultivators than the original lot. The process is known as Partial Sterilisation and is under investigation at Rothamsted[1].

[1] See Reports on Partial Sterilisation in the *Journal of the Board of Agriculture*, 1912, 1913 and 1914.

CHAPTER IV

THE EFFECT OF CLIMATE ON THE SOIL AND ON FERTILITY

THE horticulturist working under glass can have any soil and almost any climate he likes to pay for, but the farmer must accept the climate as he finds it and put up with any effect it may have on the soil and on the crop; the best he can do is to ascertain what these effects are and then prepare against them. It has been shown that they fall into three groups:

1. Climate helps to make the soil and decide the type.
2. It influences the productiveness of the soil.
3. It determines the crops that can be grown, and hence is the final agent to decide what shall be done with the soil.

The effect of climate in deciding the general character of the soil

Climate affects both the mineral framework of the soil and the nature and amount of the organic matter present.

Effect on the mineral framework. The origin of the mineral framework has already been discussed and it has been shown that two great factors determine its composition: the composition of the original rock, and the nature of the agencies concerned in the disintegration and decomposition. These agencies

are mainly climatic. The breaking down of the original rocks proceeds in widely different fashion in places where the climatic conditions are very different and cases have been observed where the differences in soil of two regions are greater than could be expected from the rocks alone; these differences are therefore attributed to climate. For example, in this country the rocks break down to yield enormous quantities of silica, the chief constituent of sand, and of various complex silicates, containing combinations of iron and aluminium, which occur largely in clay; iron and aluminium compounds, however, form only relatively small proportions of the soil. But in parts of the tropics, where the disintegration processes have gone on under wholly different conditions, the rocks have broken down to yield soils containing only small amounts of silica and relatively large quantities of aluminium and iron oxides. These soils differ entirely from ours and have received a special name, Laterite soils. In subtropical regions another type of disintegration has gone on, giving rise to considerable areas of a distinct type of red soil, in which again there is only relatively little silica. The study of these changes is very incomplete, and it is not supposed that the original rocks were identical in all cases. But it is very significant that under these three sets of climatic conditions three distinct varieties of soil have arisen, all differing in character and requiring different treatment.

There is a second direction in which climate regulates the composition of the soil. As we have already seen, the particles formed from the rocks do not remain where they are but get carried away by various

climatic agencies such as running water, ice, or wind. Usually there has been some selection and the particles became sorted out to some extent and suffered changes on the journey. The amount of sorting and the extent of the change depend largely on climatic factors.

Effect on the organic matter. The mass of mineral particles formed by weathering of the rocks and sorting out by subsequent agencies is not yet soil, although it may be looked upon as the framework of the soil. But it soon covers itself with vegetation which gradually produces the remarkable results dealt with in Chapter III and converts the mineral mass into a true soil.

The character of the soil is very much affected by the nature of the organic matter present, and this is largely determined by the type of vegetation that grows there and the extent to which the decomposition has proceeded. Now both these are climatic effects. Under dry conditions the plants tend to be narrow-leaved and tough—*e.g.*, pine needles, broom, etc.—whilst under moister conditions a larger more leafy type of vegetation arises. These two types of vegetation break down in very different manner in the soil: the large leafy plants yield a large supply of useful humus material, while the shrubbier and more leathery plants of the dry situation do not. There may be plenty of organic matter in these dry soils; the light dry sands of the Sussex heaths sometimes contain as much as 10 per cent. but it exists in the form of undecomposed bracken fronds and similar residues, and is of no agricultural value because it is not properly decomposed. Hilgard in California has shown that there is a great difference between the humus material in soils of dry and humid regions, and this difference

arises from the fact that in humid regions the conditions are favourable for the best kind of plant and the best type of decomposition to make humus material.

Soil losses

So far we have been considering only the building up of the soil; we have now to turn to the other side of the account and study the losses that are going on. The processes that called the soil into being are still operative to-day; the transport of material did not come to an end when the soil was brought into its present position but continues, and tends to remove the soil now that it is formed. The losses have gone on simultaneously with the formation of the soil and they still continue. The most important source is the rain. As rain falls on to the land and soaks in, it dissolves out some substances and carries them away. Hence the drainage-waters are always hard and often unfit for drinking. The constituent removed in largest quantity is calcium carbonate, no less than 8 to 10 cwts. per acre of this being washed away each year at Rothamsted. Other soluble constituents are also removed in smaller but nevertheless important amounts. Thus in course of time a soil exposed to a heavy rainfall tends to become reduced to hard insoluble residues of unchanged mineral fragments: finally it may become barren through loss of plant food, and "sour" through absence of calcium carbonate. On the other hand a soil in a dry region of low rainfall keeps all its soluble constituents intact, indeed it may become so heavily

charged with them as to become barren through this very excess. Again, heavy rainfall may wash the soil bodily away and leave only the bare rock or a wholly impossible subsoil. This sometimes happens in our own country in hilly regions: a serious instance occurred in 1910 in the Yorkshire Wolds north of Driffield. It is not infrequent in lands of violent storms, especially where man has come in and removed the native vegetation that once afforded some measure of protection: the eroded lands of Australia and the dongas of South Africa afford instances. Wherever some break in the surface of the veld allows the rain to start a little water-course, the washing away goes on along that line. The break may be a natural depression, or it may result from clearing the veld for cultivation or even from keeping cattle always to one track in passing to and from their drinking-places. Torrential rains soon remove the soil and lead to the remarkable erosion shown in Fig. 13. The remedy consists in delaying the water and making it run off more slowly.

Soil belts and climatic zones

We have seen that right from the very commencement of its history the soil has been moulded by the climate, and it is not surprising, therefore, that parts of the earth with characteristic climates should also have correspondingly definite soils. Wherever there is a well-marked climatic zone we may look for a well-marked soil type. In classifying soils it is necessary first to divide them into great groups according to the climate and then to subdivide these groups according to the geological origin of the material.

Fig. 13. Dongas in South Africa caused by heavy rainfall.

These zones can be recognised in any great continental area. In the great dry belt in the west of North America there is a scarcity of vegetation, consequently but little organic matter finds its way into the soil and such as does get there possesses very characteristic properties. Further, the absence of rain leads to an accumulation of soluble substances derived from the breaking up of certain mineral particles, and some of these are directly harmful to the plant while others indirectly injure it by depriving it of such little soil moisture as is present—for plants can only take water from weak and not from strong solutions. Soils thus charged with salts are called Alkali soils; these occur sometimes in patches and sometimes in great areas, but they are always dreaded alike by cultivators and travellers. For as they dry the wind blows them up into the eyes and mouth and nostrils till the membranes smart again; they carry no broad-leaved vegetation and they yield no drinking water. Patches in cultivated fields are marked by the failure of the plant. The soil is curiously mottled in appearance: it forms hard white lumps round which black water collects or dries to leave a black crust behind. It is hard on top but often mushy below, especially in irrigated regions, and after you have kicked away the surface layer you come into a thick stodgy clayey mass. Irrigation, drainage, and treatment with gypsum have done much to reclaim these lands.

Moving eastwards and northwards there is a rather moister belt with more grass and less alkali, but the vegetation is still wiry or leathery and gives rise to organic matter characteristic in quality but sparse

in amount. These are the steppe soils which can be found in parts of the Western States and of Alberta. Alkali spots still occur, and Fig. 14 shows one on a farm at Fremont, Nebraska.

Still further eastwards and northwards is a zone of higher rainfall where the conditions were such that organic matter accumulated to a very marked

Fig. 14. Alkali spot, Fremont, Nebraska.

extent in the soil. Here arose the wonderful black soils on which so much of our wheat is grown, especially developed in Manitoba, Saskatchewan and Alberta, in Minnesota and other Middle Western States.

Elsewhere, however, the black soil is not seen, but the loess, a wind-carried soil derived from glacial drift and mingled with calcareous debris but without the large amounts of organic matter of the black soils.

These give the deep rich soils found in Eastern Nebraska, Iowa and parts of the Mississippi valley. All these areas are characterised by cold clear winters and hot dry summers. In the aggregate the rainfall may be high but its distribution is not always favourable to maximum crop production. These areas are in the main treeless (see Fig. 17).

Coming still further east into the regions of wood and forest where the climatic conditions approximate more closely to our own, the soils also resemble ours in England.

A wholly different type of soil, known as the Tundra, is found in the far north in the barren lands. It is black and peat-like and the subsoil is as a rule permanently frozen: it is covered only with mosses, lichens, etc. and lies beyond the regions of our accustomed vegetation.

Any other continental area can similarly be divided into zones corresponding broadly with climatic zones. In Russia, for example, white desert soils poor in organic matter but often containing alkali are to be found in the dry Caucasian region: further north under a limited rainfall of 8–12 inches occur the brown steppe soils, their deeper colour indicating their higher content of organic matter; pushing still further north a belt of chestnut coloured soils is found stretching away in a north-easterly direction from Podolia in the south-west across Little Russia to Samara and Orenburg in the east. Above this again comes the famous belt of black earth, the Tchernozem, the nearest European approach to the black soils of the western prairies and like them devoted largely to the cultivation of wheat; these are found in Hungary and continue

north-easterly through the west Russian province Volhynia to the Government of Perm. Further north these are succeeded by the Podsols, white, poor, acid soils in a cold wet belt still left in forest; and finally above them come the Tundra soils, acid, treeless, carrying only lichens and moss.

Even in England indications of climatic zones can be traced, although in the main our soils would fall into one great group of woodland origin. But in the dry eastern counties some of the heaths are distinctly steppe-like in character, while in the wet high-lying districts of the north occur moorland soils entirely different from the clays, loams and sands of the midlands and the south.

It is not necessary to go into a detailed description of these various soils; the point of immediate importance is that the very marked and unmistakeable differences they present are the result of the climatic conditions to which they have been exposed.

The effect of weather on the soil

While climate plays a great part in determining the general character of the soil the weather is responsible for tolerably wide variations exhibited from year to year.

There are at least five ways in which the weather or seasonal effects operate:

1. High rainfall tends to wash out two very useful constituents, calcium carbonate and nitrates, both of which must be replaced or the soil loses fertility. Fortunately other useful substances are absorbed by the soil and are therefore less liable to be lost.

2. High rainfall has an adverse physical effect and spoils the tilth.

3. In dry conditions there is less or no washing out of calcium carbonate or of nitrates, and hence less wastage of fertility.

4. Drought, frost, hot sunshine, and other factors which are detrimental to life are finally beneficial to bacterial activity (p. 46), and lead to an increased production of plant food.

5. Frost has a beneficial effect on tilth.

These factors of course all intermingle in their action, but their general effects may be summed up briefly.

The nitrates formed during spring and summer by bacterial action, and destined to serve as food for the next generation of plants, are readily washed out during a wet winter, but they remain safely locked up in the soil throughout a period of frost and snow when no leaching takes place. There they lie ready for use when spring awakens the young plant into activity; consequently a mild spring following on a hard winter is commonly a period of vigorous growth. This is well seen in Canada, where a remarkable development of vegetation takes place directly the weather is sufficiently warm. In part the result is due to the effectual cold storage of the plant food, neither loss nor deterioration going on in frozen ground, in part also to the increased activity already mentioned of the food-making bacteria after a spell of adverse conditions.

Another effect of a wholly different nature is also produced. Frost puffs up or lightens the soil: it splits the hard clods and brings them down to a nice

crumbly tilth well adapted for a seed bed. Further, it tends to change clay from the sticky into the crumbly state. On the other hand long continued wetness has the opposite effect: it consolidates the soil, makes it sticky and very unsuitable for seeds. Thus at the end of a mild wet winter the soil is poor in plant food because of the leaching that has gone on, its population of micro-organisms is not highly efficient in making food, and it is in a bad mechanical condition because the wetness has made the clay particles very sticky. On the other hand at the end of a more severe winter when the land lay frostbound or covered with snow there is a good supply of plant food, all the autumn reserves having been safely locked up in the soil, the micro-organic population has become more efficient in producing plant food through the partial suppression of detrimental organisms, the texture of the soil is very favourable for the production of a good seed bed. The advantages, therefore, are wholly in favour of a dry cold winter, and we can see the wisdom of the old proverbs:

> "Under water famine, under snow bread,"
> "A snow year is a rich year,"

and of the more recent calculation by Sir W. N. Shaw that every inch of rain falling during the autumn months—September, October, and November—lowers the yield of wheat during the next season in the eastern counties by a little over 2 bushels per acre (2·2 to be precise) from an ideal standard of 46 bushels per acre.

The older writers, noticing the value of frost and snow, thought they had an actual fertilising value, and indeed many gardeners and farmers will still

contend that snow is a manure. Opinions of good cultivators are always entitled to respectful consideration, and many analyses of snow have been made, but they have failed to reveal any appreciable amount of fertilising constituents. Snow differs a little from frost in its action: it forms a non-conducting coat for the soil and prevents the temperature from falling as low as it otherwise would. Any plants that happen to be in the soil benefit by the snow cover because their roots are protected from excessive cold.

A hot dry summer has at least as beneficial an effect on the soil as a cold dry winter. The drying out certainly changes a heavy soil into clods, but when these are moistened again by autumn rains they readily fall to a good tilth. If the warmth has been sufficient there is an even more marked improvement in the soil population as far as food-making is concerned than after a cold winter.

The effect of season on the nitrate content of the soil. The manufacture of nitrates in the soil (which, as we have seen, is an indispensable process for the welfare of the crop) takes place most rapidly in our climate in late spring or early summer. It then slackens down while the plant is growing, but it may speed up again in a warm moist autumn. Typical results are shown in the curve of Fig. 15. In a dry summer the nitrate formed is all left in the soil or taken by the crop: in a wet summer some of it is washed out. This is shown by comparing the amounts of nitrate present on an unmanured fallow plot at Rothamsted during the wet summer and autumn of 1912 with those present in the dry summer of 1913. In the top 18 inches of soil amounts were found equivalent to the

following quantities of nitrate of soda, in lbs. per acre, showing a very great difference in favour of a dry summer:

	Feb.	May	Sept.
Dry summer, 1913	126	312	376
Wet summer, 1912	180	138	114
Difference in favour of dry summer reckoned as nitrate of soda ..		174	262 lbs. per acre.

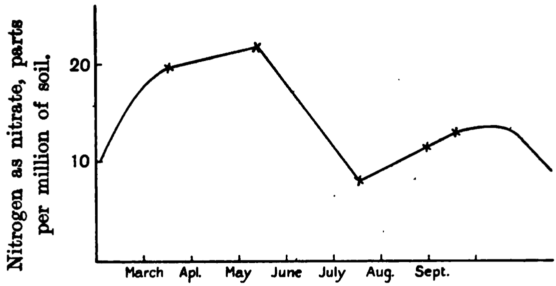

Fig. 15. Curve showing average amounts of nitrate present in cropped soils at different seasons of the year. (Rothamsted.)

The nitrates left in the soil at the end of September represent the initial stock for the farmer during the coming season. After a dry summer it is high, after a wet one low. How much of it ever gets into the crop depends on the winter weather. A wet winter will wash much of it out while a dry winter conserves it safely. During the wet winter of 1911–12 the following losses took place from some uncropped soils at Rothamsted and Ridgmont:

	Loam in good heart Rothamsted	Poor loam Rothamsted	Clay Ridgmont	Sand Milbrook
Present in Sept. 1911	690	306	234	102
Remaining in Feb. 1912	186	168	180	54
Lost during winter	504	138	54	48

Reckoned as the nitrate of soda in top 18 ins. per acre.

The loss from sand is small because the stock happens to be low, and from clay it is also small because percolation of water does not readily take place. The most serious losses are from good loams. In dry winters the loss is less, but on an average the loam at Rothamsted loses during winter months as much nitrate as would be required by a 4 quarter wheat crop.

If the student has access to drainage-water from a field he should make the following experiments periodically:

(1) Test for nitrate and compare with a standard solution to ascertain approximately the concentration (p. 195).

(2) Test for calcium. In many cases so much calcium bicarbonate is present that a precipitate is thrown down on warming the solution.

The following experiment shows how a crop affects the drainage:

Take two glazed tubulated pots (Doulton's "mixing jars" shown in Fig. 1), fill with soil, keep one pot fallow, sow grass-seed in the other. Fit the tubulure with a tight cork through which passes a glass tube bent so as to deliver the drainage-water into a bottle. Measure the amount of drainage after rain and estimate the nitrate present. The experiment must run over the whole season; in a period of drought rain-water may be *gently* supplied from a water-can, although it is hardly possible to simulate the action of rain itself.

The gauges used at Rothamsted for studying drainage problems are shown in Fig. 16.

The various bad effects of wet weather are reflected in the crop. A wet winter is notoriously bad for the

wheat crop; on the other hand a dry winter is much more favourable. Shelter of course is just as effective as dryness: the ground where a stack has stood over

Fig. 16. The drain gauges, Rothamsted, used for studying the amount and composition of drainage-water.

winter is well known to be more productive than adjoining ground that has been exposed to the rain.

The practical point arises: how can the cultivator

remedy matters? He must try both prevention and cure. Loss of nitrate can be prevented by sowing catch crops[1] in autumn to be ploughed in or folded before the spring sowings (p. 106). Bad tilth can be diminished by leaving the ploughed land rough and taking care that the wheat land does not get too fine. If the soil is already fine, as, for instance, it is left after potatoes when the digger has thrown down the ridges, the wheat seed can advantageously be broadcasted or drilled on the surface and then ploughed in and harrowed, thus exposing a new and rougher surface to the weather.

Loss of nitrate can be made good by spring dressings of quick-acting nitrogenous manures: soot or sulphate of ammonia if the surface is sticky, or nitrate of soda if the soil can be got into reasonable condition (Chapter VII). Finally the bad effect on the surface can be remedied by using the Crosskill or other roller when the land is dry, following this with the harrow.

The effect of climate in determining what crops can be grown

The fertility of a soil is judged by its power of producing crops, but it obviously cannot grow crops unless the climate allows: we therefore have to turn to the effect of climate in deciding what crops can and what cannot be grown. There is a fairly simple connection between the type of crop and the climate. In general seed does not ripen well in wet seasons or districts, and crops wanted for the sake of the seed are usually grown in dry rather than wet districts. On the other hand actual plant growth, *i.e.*, growth

[1] Particulars of suitable crops are given in the Board of Agriculture Special Leaflet, No. 28.

of leaves, stems, and roots, is much better in moist than in dry districts or seasons. For example, the abnormally dry summer of 1911 was excellent for grain crops so that the corn was uncommonly good, but it was so disastrous for the growth of grass that hay went up to two or three times the price obtained in the previous season. The wet summer of 1909 was very favourable to the growth of grass, swedes, etc., but bad for the production of seed. Another factor also comes into play. Very wet land cannot easily be dug or cultivated: if it is to be used for agriculture in these days of small profits all cultivation must be reduced to a minimum. Now the crop that requires least cultivation is grass; it is accordingly very much grown in wet districts. Since grass has to be used by animals of some sort a good deal of live stock is usually kept either for the production of meat, butter, cheese, etc., or for breeding young animals to be sold to other districts. Wherever cultivation becomes expensive for any reason there is a tendency to resort to grass and pastoral conditions.

The following rules will be found useful in discussing crop production in temperate regions; they are, however, by no means absolute. Warm districts yield early crops, and are therefore well adapted for market garden produce and for fruit. Moderately dry regions are suited for seed crops. Moister regions are adapted for seed crops that need not fully ripen such as oats, for root crops like mangolds, swedes or potatoes, or for leaf crops like the cabbage tribe. Wet regions are commonly devoted to grass.

These same factors that determine the regional distribution of crops operate everywhere and many

illustrations of their action may be found within very restricted areas.

Land lying at the bottom of a slope is moister than land lying higher up, because it receives the water that has drained down from above as well as its own share of the rainfall. Sometimes it is so wet that it forms a marsh unsuited for cultivation and therefore left in grass; the land immediately above is then commonly used for general crops. But where the water level is well below the surface of the soil the bottom land is not marshy but is on the contrary highly fertile and is more regularly supplied with water than the higher land. Land at the top of a slope may be too exposed or too cold for cultivation, and often if it lies above 700 ft. in England it is left either as grass, wood or waste; the limit is higher in places, *e.g.*, the milder parts of Wales, the Yorkshire Wolds, etc.

The following is the typical sequence in travelling up a valley or a slope in England. If the bottom is marshy, grass only is grown there, if it is dry, good crops of roots, cereals or other plants can be obtained; higher up arable crops are grown or, as we shall soon see, fruit; still higher comes grass land, especially in the cold north, while above the 600 or 700 ft. contour is wood or waste land.

The small difference in temperature between a north and a south slope may have a considerable effect on the crop, vegetation on a south slope being a little more forward and ready for market before that on the north. In ordinary agricultural practice this is not usually of much importance but it is for market garden work; amazing differences in price

are often attached to small differences in time of marketing.

More important, however, than high mean temperature is the absence of spring or autumn frosts. Low lying valley lands are peculiarly susceptible to frosts on clear calm nights; the cold air drifts down from above and collects in the valley where it chills the trees and not infrequently kills the fruit blossom and the tender shoots of early potatoes. Land lying above this stagnant pool of cold air escapes these frosts and is therefore a safer place for susceptible crops, even though its mean temperature may be lower than that of the valley. Where, however, the low land adjoins the sea or any great body of water it is protected from these frosts and is, indeed, better than land lying further off because it is warmer.

We can now understand why fruit is so often grown in undulating country. Slopes are needed to give the desired shelter and aspect, but above all to avoid risks of late frosts. The "lucky banks" of the Evesham district, on which crops can nearly always be got, are of this character. In the fruit-growing region of Kent the fruit tends to collect on the middle slopes, hops on the lower ground (or wood, if the ground is wet), and woodland or nuts on the higher ground. But near the sea—and this holds generally round the coast—fruit can be grown with advantage on the lower ground.

Climate and soil, however, do not entirely determine what crops shall be grown, although they certainly play a great part. Agriculture is always pursued for profit, and the cultivator does not necessarily grow the crop that naturally *does* best on the land, but

the one that *pays* best. Thus a set of economic factors comes into play, working along with the climatic factors and with them determining what crops shall and what shall not be grown. It is impossible to overlook these economic considerations in any real study of soil fertility, but as we must keep our subject within reasonable bounds we can only indicate their general nature.

As the produce of the land has to be sold it obviously must be got to the market; chief among the economic factors is therefore the question of transport. From this point of view live stock presents least difficulties; animals can be made to walk to market while crops have to be carried. Sheep, cattle, and horses therefore tend to become the mainstay of agriculture in countries destitute of transport facilities. But where transport is possible wheat or maize becomes the most convenient product, for either will keep almost indefinitely so long as it remains dry, suffering little if any deterioration, however long the journey to market may take, and, what is more important from the settler's point of view, both are always saleable. On the other hand, fruit and vegetables will not keep and can only be grown where transport facilities are good.

History repeats itself with but little variation in the agricultural development of virgin countries in temperate regions. At first the country is pastoral. Then with the opening of railways comes wheat or maize production. Later on when the country is more closely settled other crops are raised and wheat loses its premier position: oats are wanted in enormous quantities for the horses used in railway and other construction work, green crops are needed for the

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Treeless prairie, first stage of development.
Ranching (Sounding Lake, Alta.).

Treeless prairie, last stage of development. An Experimental Farm (Indian Head, Sask.).

Fig. 17. Development of prairie land, Western Canada.

cattle and sheep, and other crops are wanted to satisfy the more exacting needs of the population that follows the simple-living pioneer. Then as transport becomes still easier fruit and vegetables are raised in suitable districts for shipment to the cities or abroad (Fig. 17). Canada, South Africa, Australia and the United States show all these stages of development. Finally, when wealth has accumulated and brought leisure and freedom from the struggle, there arises a fastidious people that picks and chooses and puts a price on subtle differences in quality inappreciable to the unsophisticated. Fashion, prejudice and sheer boredom now become factors and lead to demands for particular varieties of particular crops grown in some special manner: so high a price is offered to anyone who will provide these things that the supply is soon forthcoming.

The position to which all these observations lead is this: climatic considerations dictate what crops can and what cannot be grown in a given region; they further modify the soil and thus affect the ease of raising the crop. Economic considerations such as transport and market price determine which of all possible crops shall actually be grown. All this leads to much specialisation in crop production as is demonstrated by the crop-map of Great Britain (Fig. 18). The warm districts of Cornwall, the Channel Islands and parts of the Ayrshire coast yield early crops; the dry districts of the eastern counties produce wheat, barley, peas and seed. The cooler moister regions of Cheshire, the Fens, the Wash, and the Lothians produce potatoes; oats and swedes are raised in moist regions, while in still wetter districts grass and dairying come in. Wherever the climate is satisfactory and

the railway connections good an industry springs up in fruit and vegetables. Finally, the higher or less

Fig. 18. Crop Map and Isotherms of Great Britain.

accessible districts are given up to the raising of live stock to be fattened out in those favoured districts

where animal food grows more quickly than the animals born on the spot can consume it.

To some extent it is possible to modify the dominating effects of climate on crops; there is a little elasticity in both directions. Plants are somewhat plastic and can be moulded to a certain degree in the plant breeder's hands; they can be bred to tolerate greater cold or more drought than usual. Thus in Canada wheats are being produced to grow further north than ordinary kinds so as to take into cultivation a belt of land at present suited only for grass. In Australia wheat has been bred to tolerate drought and grow in the drier regions. This sort of work is being done very widely and we do not yet know how far it can be pushed.

Climate apparently cannot be altered; indeed, we can only get over some of its bad effects in one direction. Temperature is at present beyond our control; the hot regions remain hot and the cold regions remain cold and we cannot alter matters. Wet districts can be improved somewhat by drainage. Our great triumph, however, is in the dry districts. Irrigation and the special agricultural methods known as dry farming have brought into cultivation enormous tracts of land, hitherto desert, in India, South Africa, Canada, Australia and Egypt, while a great project is on foot for Mesopotamia. But the mention of Egypt and of Mesopotamia reminds us that our modern triumph is no modern invention. Egypt and Mesopotamia were irrigated long before our civilisation appeared; the farming methods of the Syrian peasant handed down by long tradition contain in them all the principles of our modern dry farming.

PART II

THE CONTROL OF THE SOIL

CHAPTER V

CULTIVATION

In the preceding chapters we have been dealing with the soil as it stands in the field and studying the changes which it undergoes in the natural state. We now turn to the second part of our subject: the methods whereby the farmer can utilise the soil to the greatest advantage and make it yield crops in quantities that repay the time and trouble involved.

Two courses are open to the farmer: he may be content with the soil as it is, or he may try to improve it. The first is much the simpler plan and has perforce to be adopted in many parts of the colonies: the improvement of the soil is a more serious affair, and is looked upon as being in part at any rate the landlord's business. The distinction is so important in practice that special terms are used to express it. The word " heart " or " condition " denotes the state of the soil as it stands; a soil being in good " heart " when the farmer is working it for all it is worth, cultivating and manuring it wisely and well but not effecting any costly improvements. " Fertility " is used to

express the inherent capabilities of the soil which can only be improved by costly operations usually undertaken by the owner of the land. The distinction is not as real as it looks, " condition " and " fertility " are simply different degrees of the same thing, and they are separated only as a matter of convenience. In this chapter we shall deal with the simpler case only, and shall discuss the cultivation processes which make full use of everything in the soil without, however, permanently improving it.

Practical growers have long since discovered that crops will not grow unless the land is properly cultivated, and indeed the connection between cultivation and crop growth is so close that much of the improvement in farming in the last century must be put down to improved methods of cultivation, while much of the success of the best farmers in growing large and vigorous crops to-day arises from the complete mastery they have gained of the cultivation of the soil. Winter and spring work on the land consists largely in the preparation of the seed bed, and unless this is properly done the crop runs great risk of failure.

It is our business in this chapter to study the reasons for the various cultivation operations and to ascertain what effects they produce on the soil. There is still a good deal to be discovered but sufficient is known to indicate the broad outlines of the subject.

The first object of the cultivation is to get the soil into a good " tilth," *i.e.*, to make it assume the nice crumbly condition which long experience has shown is best suited to the growth of plants. The important fact here is that the clay can exist in two states—the sticky and the crumbly state: and it is

such a dominating substance that it confers these properties on the soil. In consequence any soil which contains more than about 10 per cent. of clay may appear in two very different guises—either in the nice crumbly condition of a fine tilth, or in the other state when it is sticky after a spell of wet weather, and dries into hard clods in dry weather.

Winter cultivations. Two of the great objects of winter cultivation are to ensure that the land shall dry quickly in spring and that the clay shall take on the proper crumbly condition. The former is secured by leaving the land in a rough state so that a considerable surface is exposed and also by arranging that water can easily get away. The latter is effected by a combination of good cultivation with the addition of lime, chalk or limestone, and of organic matter, and by exposure to frost. On the other hand long exposure to water (*e.g.*, a long wet winter), alkaline substances such as liquid manure, large excess of certain fertilisers, and general bad management, all tend to change the crumbly into the undesirable sticky state.

We are at present only concerned with the cultivation process: the effect of lime and organic matter is dealt with in the next chapter.

The actual mechanical part of the process of breaking up the soil and exposing it to the frost does not concern us here. But the time of the operation does, because the exposure of the soil to weather not only means that it is carrying no crop, but may mean considerable loss of plant food. A soil that is at all light or porous readily loses its valuable nitrates, and although the loss is not so serious on heavier loams and clays, it takes place even there. The loss

only seems to go on, however, in wet weather and if one could rely on having the ground frozen hard throughout the winter it would be simple enough to arrange about cultivation; one would turn the ground up roughly at the beginning of the winter, and leave it to the end. Unfortunately, our winters are variable, and land turned up in autumn may only occasionally get frozen, and may lie wet for long periods; it then derives very little benefit from the cultivation, and suffers considerable loss of plant food.

It must, therefore, be arranged that the cultivation effect is at a maximum, while the loss is at a minimum. The general rule is that light soils may be left uncultivated until late in the winter or early spring, partly because the amount of frost they require is only small, partly because the loss that they would suffer in rain is very large. Heavy soils, however, should be turned up as early in the autumn as possible because they require a large amount of frost, and suffer only little loss. The rule, of course, requires intelligent application and adaptation to each locality.

The effect of winter cultivation in lightening the soil is well seen in the following experiment devised by Mr F. J. Gurney. Mark out a plot of ground one rod square and divide it up into square yards; at the corner of each square dig a hole 12 inches deep. Place a brick at the bottom of each hole and on it stand an iron rod 16 inches long (and therefore projecting 8 inches above the surface of the soil) and put in sufficient concrete to hold the rod rigid: then fill up with earth. The plot will now be provided with 25 fixed posts projecting out from the soil (Fig. 19). Lay a straight edge from post to post and measure

with a ruler the depth of the surface below it. The posts being fixed this straight edge is a fixed base line which enables you to follow the change in level of the soil at any time. Divide the plot into two parts, leave one alone and dig the other deeply, leaving

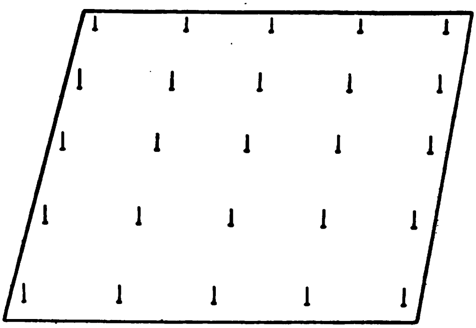


Fig. 19. Plot of land with fixed pegs for cultivation experiments. (Mr Gurney's experiment.)

the surface approximately level. The following are some of the results obtained:

	Level of soil below straight edge						Mean
Before digging ..	6½	5½	6½	7	7	7	6½ inches
After digging ..	4	3	3	3	3	4	3⅓ ,,
Raising of surface due to digging ..							3 ,,

Readings should also be taken after a heavy downpour of rain, and after a good frost to show how these affect the soil.

Spring cultivation. The object of the spring cultivation is to complete the winter cultivation and obtain a tilth suitable to the crop. The operations depend on the fact that *if the clay is in the proper state* small lumps of soil readily fall to pieces when just sufficiently

moist. Hence after winter the soil is allowed to dry and is then broken down into small lumps by a clod-crusher: these are then allowed to become moist so that they break to pieces with harrows. The operation probably demands more skill and judgement than any other part of soil management: both the drying and the rewetting are done by the weather and are therefore largely out of farmers' control; only a limited time is available and the season for sowing the crop soon passes; and, on the other hand, if the farmer tries to hurry matters too much and begins before the land is dry enough he may poach it so badly as to ruin it for a time. His only chance, therefore, is to have his work well forward in autumn and winter so as to take full advantage of favourable opportunities in spring. The ideal case arises when the soil was turned up roughly in autumn, when the winter was frosty, and the spring just sufficiently showery to soften the lumps at the proper time and facilitate their breaking down under the harrows. A mild winter makes matters more difficult because the clay does not flocculate. If the early spring is dry the soil dries to a hard surface, or, in the case of lighter soils to steely lumps which can be broken by the Crosskill or other roller; if, however, the spring remains dry there is great difficulty in getting any further and obtaining a proper tilth; this is often experienced on the loams of the south-eastern parts of England where spring rainfall is low and winters are mild. A good cultivator watching his opportunities often achieves remarkable results, but no one has yet succeeded in reducing his art to an exact science.

The most difficult case arises when the winter is mild and wet and the spring wet so that the soil never

dries for the preliminary breaking down into small lumps. The heavier the soil the worse the trouble: and seasons of this kind have sometimes proved disastrous. No way round the difficulty is yet known, and this is one reason why heavy soils are often not brought into arable cultivation.

Rolling. It has already been stated that frost puffs up and lightens the soil and where the soil is already rather porous the effect may be actually harmful to the plant. It is essential that sufficiently close contact should be maintained between the soil and the root, otherwise the plant does not obtain the proper supply of water and nutrient salts; wherever the winter frosts have so puffed up the soil as to reduce this contact too much it is necessary to compact the soil again by rolling. These effects are produced by the furrow presser used for all cereal crops on light chalky soils, and for wheat after a ley on many other soils.

Another factor comes into play on grass land. Earthworms burrow in the soil and throw out material from below on to the surface. These casts accumulate steadily at a rate calculated by Darwin to be about one inch in ten years. The worms honeycomb the ground with their burrows, and this action, though necessary to the plant, becomes after a certain stage harmful and injures the grass while allowing moss to grow.

Fortunately the remedy in both cases is simple: the ground should be rolled during dry weather in spring until the proper degree of compactness is reached. This operation is very necessary on chalk soils, sandy loams, and grass land.

Summer cultivation consists in hoeing and its object is two-fold: to keep the surface of the soil in a fine

state and to kill weeds. A layer or "mulch" of fine soil keeps the land cool during hot weather and prevents loss of moisture. This can be shown by the following experiment:

Set out three plots each 3 ft. × 3 ft.: leave one alone entirely so that it may cover itself with weeds: keep the second clean by hand weeding but do not touch it otherwise: keep the third well hoed. Take readings of the temperature of the soil at depths of ½ inch, 3 inches and 6 inches below the surface: in particular obtain readings on hot sunny days and on cold windy days. Periodically also take samples for the determination of the moisture content: this is done by driving in the borer (Fig. 33, p. 194) to a depth of 6 inches, weighing the soil that is withdrawn (or a fair sample of it), leaving to dry in a warm place and then weighing again. Table II gives some of the results which have been obtained.

TABLE II. *Effect of hoeing on moisture content and temperature of soil*

	Hot sunny day		Cold sunless day	
	Untouched	Hoed	Untouched	Hoed
Soil temperature ½″	35°·0 C.	31°·5 C.	17°·5 C.	17°·0 C.
,, ,, 3″	30°·5 C.	28°·8 C.	16°·7 C.	16°·3 C.
,, ,, 6″	27°·0 C.	26°·5 C.	15°·8 C.	15°·5 C.
Soil moisture, per cent.	14·7	16·0	19·3	18·4

Hoeing reduces the temperature and economises the water supply of the soil on hot sunny days, but it seems to have no such effect in cold sunless weather.

In our country there are so many cold sunless days that it is doubtful whether constant hoeing would be worth doing on a farm, although it is often found to be advantageous in market gardens by reducing the necessity for artificial watering. But in sunnier drier climates the gains in soil moisture are more pronounced and are worth obtaining even in farm practice: it is then customary to send out the disk harrows and start surface cultivation directly a shower of rain has fallen, and before the land has had time to dry up again. This is the central idea of "dry farming."

Under moister and cooler climatic conditions probably the chief effect of hoeing is to keep down weeds. This is indicated by an interesting experiment that has several times been made, but not with sufficient exactness, in which a crop is grown (*a*) without any hoeing or attention; (*b*) not hoed, but weeds were carefully picked off; (*c*) hoed. The neglected plot becomes infested with weeds and the crop does very badly, but there is usually not much difference between the hoed plot and the one where the weeds were simply pulled out. The student should try it for himself. The result is very important; some of the older soil workers thought that the actual stirring of the soil was beneficial, but if wider experience showed that the only effect was to kill weeds an important piece of knowledge would have been gained.

This leads to the second important aspect of cultivation: its effect in keeping down weeds.

Cultivated plants cannot usually survive competition; there are of course exceptions and everyone knows the type of plants that crowd out all their

neighbours. Nevertheless the mere fact that these are spoken of as "growing like weeds" proves how exceptional is the character. The bad effect of a high hedge is notorious while the damage done by a single large tree may amount to as much as 4*s*. a year. Mr Pickering has shown that the damage is mutual and that the tree also suffers considerably[1], at any rate when it is young. Weeds in particular have to be excluded as much as possible from the crop and the most effective way of doing this is by cultivation. The best farmers always have their land cleanest, and not only do they secure bigger crops and higher quality but they have nothing to waste.

Fallowing, or leaving the ground free of crops, gives the farmer a free hand for his cultivations, and it also appears to allow the soil bacteria more scope for carrying out their useful work.

Recent investigations indicate that the growing plant may in some way interfere with bacterial activity in the soil and reduce the amount of nitrate produced. Thus there is less nitrate present on cropped land than on fallow land even after allowing for what has been taken up by the crop. The following data were obtained at Rothamsted:

	N as nitrate, lbs. per acre			
	June 1911		June 1912	
	fallow	wheat	fallow	wheat
In soil ..	54	15	46	13
In crop ..	—	23	—	6
Total ..	54	38	46	19
Deficit in cropped land		16		27

[1] Reports of the Woburn Experimental Fruit Farm, especially 14*th Report*, 1914.

Indeed, wherever the climate allows, it is good practice to plough very early in autumn and cultivate well so as to kill weeds and to give the bacteria a good chance of storing up nitrates for a winter-sown crop. It may even be profitable to secure an earlier start by sacrificing the aftermath of the seeds ley. On heavy land it is sometimes found worth while to spend a whole season over the fallow, sacrificing rent, rates and capital charges, so as to allow ample opportunity for obtaining these various effects of spring and summer cultivation.

Subsoiling and trenching. The object of these operations is to increase the root range of the plants.

In ordinary circumstances plants do not have a great deal of root room: the surface layer, which alone is well suited to their requirements, is only about 5 or 6 inches deep—not always as much, indeed—and it is usually underlain by a subsoil which is not particularly suited to the plant and from which its roots cannot draw much nourishment. Any process that makes the subsoil a better habitat for the roots increases the extent of the root range and therefore enables the plant to make better growth. The obvious method of improvement is to make the subsoil more closely resemble the surface soil, and in designing the necessary cultural operations it is necessary to bear in mind the distinctions already set out (Chapter II) between the surface and the subsoil, viz., the presence in the subsoil of less food, less organic matter and less air than the surface soil, and the presence of more clay, which is likely to be in the undesirable sticky state.

The improvement of the subsoil is not commonly attempted in farm practice excepting only on arable

soils where a plough-sole has been formed through the constant tramping of the horses, or where a pan occurs near the surface; recourse is then had to subsoiling, and often with considerable success. The operation is not necessary oftener than once in four or five years, and it can well be done as part of the preparation for the root crop.

In market gardening and horticulture it is common to trench the land, and owing to its great importance this process requires some consideration. We have already seen in what characters the subsoil differs from the surface soil, and the object of this type of cultivation is to make the two more nearly alike. One difference between them lies in the amount of plant food they contain. Sixty years ago it was thought that the subsoil was really the virgin soil, rich in stores of food that only needed liberating by the action of frost. Sixty years of experiment have shown that this is not correct; the subsoil is really very poor in plant nutrients, and nothing whatever is gained by bringing it to the surface. Considered as a manure it is despicably poor. This is the general rule; exceptions arise when the subsoil contains much chalk or marl, and the surface soil does not; or when the subsoil is clay, and the surface soil is too light a sand. With these exceptions the subsoil is much poorer than the surface soil, and therefore to make it equal the gardener must add manure to it.

To get the subsoil into the same mechanical condition as the surface soil is not easy because frost does not penetrate readily. Something can be done, however, by adding lime, limestone, chalk, or basic slag, to the subsoil at the time of trenching.

The roots of the plants have a wonderful facility for boring their way into the subsoil, and very stout roots can often be found well below the surface depth. It is not clear, however, that the loosening of the soil is particularly helpful to these plants, indeed a soil which is simply loosened and then left soon settles back to its natural condition.

Three methods of trenching have been used:

1. The top spit is kept on the top, and manure is buried in with the subsoil.

2. The digging is done in the same way but no manure is added, the subsoil being simply loosened.

3. The subsoil is put on the top and the surface soil below.

These three methods have given rise to much discussion but there are times when at least two of them are sound.

The first is practically always beneficial, though it is not always a commercial success.

Recent experiments at the Woburn Fruit Farm and at Rothamsted have shown that the second method (the loosening of the subsoil without additional manure) has very little effect either on the water content, the amount of plant food or the growth of fruit trees. There is no evidence that this operation is worth doing; the gardener who takes the trouble to trench should certainly not miss the excellent opportunity it affords for putting the very necessary manure into the lower spit.

There are, however, cases where the third method (the inversion of the surface soil and bringing up of the subsoil) has worked very well, particularly on sandy soils where the difference between the surface

and the subsoil is much smaller than it is on the loams and clays. The subsoil is not particularly unsuited for the growth of plants, and when it is brought up to the surface it only requires proper manuring to enable plants to make a satisfactory start. Then when the roots grow down to the second spit they come to the old surface soil and develope well: thus in the end they range over two spits whereas on untrenched land they cover one spit only.

We can now make a general summary of the effects of cultivation; they are:

1. To change the clay—and therefore the soil—from the sticky state which is bad for plants to the useful crumbly state.

2. To keep the surface fine so as to reduce the temperature and conserve the water supply on hot fine days.

3. To give the crop a clear field for growth and reduce competition by weeds: this seems also to enable the bacteria more rapidly to accumulate nitrates in the soil.

4. In horticultural and market garden practice to change the subsoil and make it as nearly as possible like the surface soil.

CHAPTER VI

THE CONTROL OF SOIL FERTILITY

We now turn to the final part of our subject: the study of the methods by which the fertility of the soil may be increased, or, in other words, the soil may be made more favourable for the growth of plants. It will be remembered that the plant requires from the soil six conditions, viz.:

1. Proper water supply.
2. Proper air supply.
3. Suitable temperature.
4. Nutrient salts.
5. Ample root room.
6. Absence of injurious substances or pests.

Further, these six are all quite distinct: it is no good satisfying five of them if the sixth is not attended to: any single one left unsatisfied may operate as a limiting factor and render the soil infertile.

Thus the problem of increasing the fertility of the soil reduces itself to the discovery, first of the factor or factors limiting the growth of the crop, and then of the best methods of overcoming the limiting factors.

Sometimes the fault lies with the soil, sometimes with its surroundings: in the first case the defects may be called *intrinsic*, in the second *extrinsic*. It is necessary carefully to distinguish between these: there is obviously no point in spending time and money in doing something to the soil when the surroundings are unsuitable, or in elaborately trying to improve the surroundings when the soil is not worth it.

The distinction is well illustrated by the following experiment due to S. T. Parkinson[1]. A trench 5 ft. broad, 30 ft. long and 3 ft. deep was dug out: the sides and bottom were lined with loose bricks and stones, and four partitions were put up. The divisions were then filled respectively with a good loam, a peat, a gault clay, a poor sand and broken

Fig. 20. Carrots grown on various types of soil.
(S. T. Parkinson's experiment.)

chalk. Carrots were sown and gave results shown in Fig. 20. The student should repeat the experiment using typical local soils. The observed differences depend on the intrinsic properties of the soil, the extrinsic conditions being the same for all.

The chief *intrinsic* conditions are that the soil must be capable of going into a good tilth, that it must contain enough of all the constituents required

[1] *Journ. South Eastern Agric. Coll.*, Wye, 1910, 258–261.

for the plant and that it must not be "sour," while the most important *extrinsic* conditions are that it must be sufficiently deep, sufficiently supplied with water during the growing period of the plant, and exposed to suitable climatic conditions.

Perhaps the most widespread soil defect is "sourness" or "acidity." "Sourness" is a state that cannot easily be defined although a good cultivator easily recognises it. It arises through lack of lime and shows itself in a bad physical state of the soil and in the poor growth and obviously unhappy appearance of the vegetation, especially of clover. It is partly due to deflocculation of the clay but apparently partly also to the presence of certain harmful substances formed under these special conditions. Unfortunately few investigations have been made in this country on "sourness," but it can be cured by additions of lime and proper cultivation. "Acidity" can be recognised readily by litmus paper; a blue piece changing to red in contact with an "acid" soil. Until sufficient lime has been added to correct "sourness" or "acidity" no scheme of husbandry is likely to be successful.

As a general rule no soil is satisfactory unless it can be got into the nice crumbly condition or "tilth" which the gardener aims at in preparing a seed bed. This requires that the clay should be flocculated, which, as we have seen, can be done by (1) adding lime or chalk, (2) adding organic manures, (3) leaving the soil turned up and exposed to winter frosts, (4) cultivating the soil only when it is in the right condition and carefully refraining from touching it when it is too wet. Heavy clay soils can rarely be got into a good tilth and hence are unsuitable for

cultivation: light soils easily acquire the proper tilth: in between come a whole series of soils which a skilful farmer can manage while an unskilful one cannot. But it may be taken as a guiding principle that if a good tilth cannot be secured either the soil or the man is at fault and failure is almost certain to follow.

Again, the soil must be sufficiently deep. Even the best soil would prove infertile if it were spread out too thinly on a rock or a gravel bed, or if it were waterlogged to within a few inches of the surface. Most soils are improved by being deepened, but before deciding how to proceed a careful examination has to be made on the spot. The simplest case arises when a thin layer of rock parts the surface soil from the subsoil below: sometimes such a layer has been formed in recent times and is known as a pan. So long as this remains it effectually checks plant growth. When it is broken up and removed a greater depth of soil is at once formed and plants develope much more readily. An example of this improvement on a large scale is furnished by Cox Heath, Maidstone, once a waste, now a fertile tract[1].

Sometimes, however, the rock is solid and then it obviously cannot be removed. If it lies in regular layers end on to the surface there is the possibility that some of the roots may be able to find a way in between, as happens in the Upper Greensand beds of West Sussex, but if the layers lie horizontally the chance of success is much smaller. The case becomes still more difficult when the soil lies on gravel. The "shrave" of West Sussex, the commons of

[1] This and other reclamations are dealt with more fully in the author's *Fertility of the Soil*, Cambridge University Press, 1*s*. net.

Hertfordshire, are formed of thin soils lying on gravel which could never be managed satisfactorily in spite of the fact that good farmers have always been found on the deeper soils round about them. Modern science has as yet no way to suggest (Figs. 21 and 22).

When the shallowness of the soil is due to water an obvious remedy consists in lowering the water table by drainage. Over a large part of England this trouble did exist, and one of the greatest achievements of the 19th century was the extensive drainage that was undertaken. Some of it, of course, was done badly, the drains being put too deeply, and some of it wants doing again especially where the pipes have got blocked up, but the improvement was great and lasted for a long time.

Bad drainage is one of the common causes of infertility on heavy soils in this country. It was met in the old days by laying up the land in high ridges several yards wide (often a rod wide) which were commonly not quite straight but curved at each end like a long drawn out S, the result of a difficulty in turning the ploughs in the days when a long team of oxen was used. The scheme had the drawback that the furrows were usually too wet and too much on the subsoil for a satisfactory growth, and sometimes the plants failed altogether. Even a shallow furrow has a bad effect. Moreover the advent of the binder has necessitated the use of flat ground and made the old ridges impossible.

From 1823, when James Smith of Deanston, Perthshire, began to draw attention to drainage, large areas of land have been pipe-drained. The cost is high and in many cases the result must have involved

Fig. 21. Harpenden Common. Land that cannot be cultivated because it is a thin soil lying on gravel.

Chalk subsoil. This land can be cultivated although the soil is thin. (Harpenden.)

Gravel subsoil. This land cannot be cultivated because the soil is too thin for a gravel subsoil. (No Man's Land, Wheathampstead.)

Fig. 22. Influence of the subsoil.

financial loss although the contingent benefits in the countryside were probably worth it. In the old days there was a great dispute as to how deep the drains should be laid: Smith laid shallow drains, and Josiah Parkes, a famous engineer, who drained Chat Moss and other great areas, laid deep drains. It is now known that both sides had a good case: shallow drains are needed when the water to be removed comes from above—*e.g.*, from excessive rain or seepage from high land—and deep drains when the water is thrown up from below. Before deciding on the depth of the drains, therefore, it is necessary to ascertain where the water is coming from and how and where it can best be intercepted.

On clay lands the water usually comes as rain and therefore shallow drains are best. The pipes are commonly 3 in. diameter and are often laid 2½ to 3½ ft. deep and at distances of 15 to 30 ft. apart, but an intelligently thought-out plan is always wanted. The cost is considerable—it is put at about £7 per acre—and where it is undesirable to spend so much money a mole plough often furnishes a cheap and tolerably efficient substitute especially where there is a reasonable fall to a ditch. This implement cuts out a 3–4 inch tunnel 18 in. to 3 ft. below the surface of the soil into which the water can drain. The tunnel is more permanent than might be anticipated, and may be expected to last 15 to 20 years or more, especially if it does not run straight into the ditch but into the old mains, or, if these cannot be found and cleared, into new pipe drains discharging into the ditch[1].

[1] See paper by D. T. Thring, "Mole-drainage and the renovation of old pipe drains." *Journ. Roy. Agric. Soc.*, 1914, LXXIV. 76–89.

Whatever the drainage scheme it is particularly important that the ditches should be kept clean and the outfalls of the drains open: the main drainage brook of the district must also be cleaned regularly. If the land is not wet enough to need actual pipe drains it may still require a water furrow to carry away excess of rain, and, should no natural outlet occur, a sump or a dell may be made, as is done in parts of Hertfordshire. The great point is that water must not stand about on the land.

It is not enough that the soil should go into a good tilth and be of sufficient depth: it must also contain all the things wanted for the proper growth of the plant. The soil, in short, must be complete, containing adequate quantities of sand, silt, clay, calcium carbonate, organic matter, and the various nutrient salts. Many natural soils are lacking in some direction or another, but it is usually possible to make good the defect. The farmer, however, wants more than this: he wants to make a profit on the transaction, and therefore a compromise usually has to be effected between the ideal and the commercial. Sand can be added if necessary, but 100 tons or more would commonly be required per acre to make any appreciable difference. This would cost too much to be practicable in England although it can be done in countries where labour is very cheap. Clay can be added at less expense because a dressing goes further than in the case of sand: the operation becomes a commercial possibility when the clay contains calcium carbonate[1], so that two desirable constituents are added in one operation. Illustrations are afforded in the Isle of Ely, where

[1] This mixture is called Marl.

such clay is obtained from below the surface. The method consists in laying trenches, 18 yards apart, and in each digging holes ten to the chain and sufficiently deep to reach the clay: about a ton is then got from every hole and spread round about. The cost of the operation is some 50*s*. per acre. A considerable area of land in the Pays de Waes, between Antwerp and Ostend, was improved in this way.

Chalk or lime is still more easily added: some 20–40 tons per acre of chalk are needed, but much smaller quantities of lime suffice. Organic matter can be added in two ways: either by adding farmyard manure or other organic manures, or by green manuring. The nutrient salts can also be added in the form of various manures.

The question of improving soil in many cases therefore reduces itself to one of cost. It has become the practice in this country to regard the more costly and permanent methods—such as drainage—as the landlord's business, and the cheaper and more transient methods—such as manuring—as the tenant's business for which, however, he is compensated if he quits the holding before a certain interval of time has elapsed. Now the landlord is not always able or willing to expend money on costly improvements and the question then arises: what line is the tenant to take?

In deciding what to do the farmer must remember the universal law that the plant must have all its requirements satisfied and excess of one cannot replace insufficiency of another. He must therefore get over each defect as he discovers it. First the obvious defects must be corrected. Thus if the soil is water-logged it is no use putting on manure until a way out

has been found for the water. The farmer may be able to do this by means of a few trenches or mole-ploughing, but if he cannot the water will set a limit beyond which his crops will not grow: it is therefore useless to spend time and money in trying to make them. Next a good dressing of lime, limestone or chalk must be given. Then if there is a pan or plough-sole, or if the land has obviously only had shallow cultivation for a long time, recourse must be had to subsoiling or deep ploughing. In bad cases a fallow must be taken, but ordinarily a root crop allows all necessary cultivations for improving the state of the soil.

In drawing up the scheme of husbandry crops must always be chosen that suit the conditions: only the horticulturist can afford to attempt plants not naturally suited to the soil. Even different varieties of the same crop show different preferences, and marked improvements in yield can often be obtained by getting true seed of a variety that happens to suit the general conditions of the farm. There is great scope for the plant breeder in this direction. However, even after the most suitable variety has been discovered there may still be something lacking in the soil or something that keeps down the crops to a certain level: the farmer should always work up to this, but he must realise that he cannot get beyond it. Table III gives an illustration from the Rothamsted field plots: the land as it stands, without any addition of manure but cultivated well so as to get a good tilth, yields on an average 13 bushels of wheat and 13 bushels of barley, but never more than 20 and 26 respectively[1]: when suitable plant nutrients are added to

[1] In 1854 and 1857 respectively: not since.

the soil these yields are increased to 32 and 43 bushels. By improving the rotation the yield can be pushed up a little, and so it can by adding chalk, but the Rothamsted soil never gives as good wheat yields as can readily be obtained at less expenditure on manure on the brick earths of the south-east of England, and *it would be useless for a farmer to buy manure to try and make it*: the soil type is the limiting factor

TABLE III. *Yield of wheat from various soils, bushels per acre*

	Good wheat soil	Soil less suited to wheat. Rothamsted		
	Sussex brick earth	Unmanured	Dung	Artificial manures. Very heavy dressing
Good years:				
1885	54	15	40	37
1887	50	15	35	35
1899	53	12	43	39
Bad years:				
1879	32	5	16	21
1892	27	9	33	38
Average of 5 years:				
1900–1904	44	10	33	39
1905–1909	42	13	38	41

(Fig. 20). And so with most soils: the tenant should work them up to their full capacity but there is a limit beyond which he cannot go. If this limit is to be passed it can only be done by means of some big permanent improvement which should be undertaken by the landlord if it is to be done at all, but

which may not be worth attempting because the climate may prevent better growth.

The history of agriculture affords many instances of the way in which the yield is pushed up by steadily

WHEAT SOILS

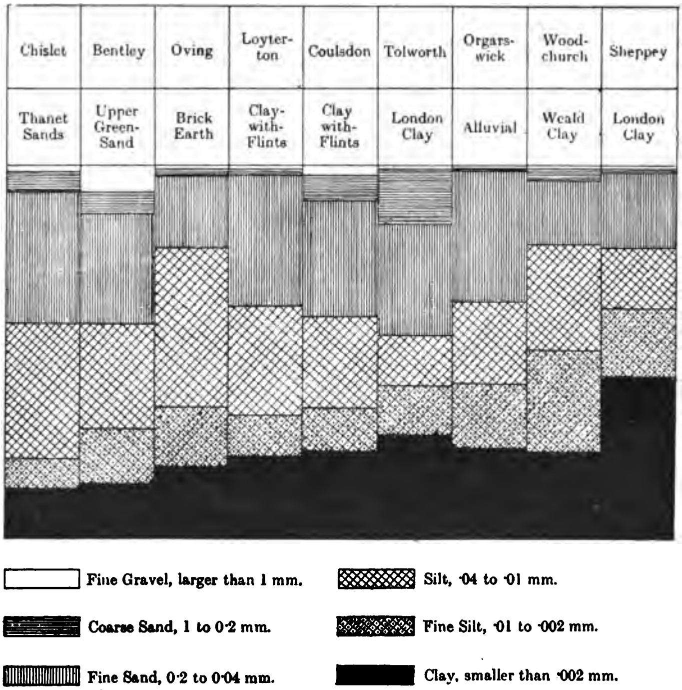


Fig. 23*a*. Mechanical composition of soils well adapted for certain crops.

removing the limiting factors that had been keeping it down. From the medieval writers we may infer that 10 bushels was a common crop of wheat in their day: this was obtained on unenclosed land by the

use of such stable manure as could be got. Later on, when the land was enclosed, it could be kept cleaner: competition of weeds was therefore reduced; still later

POTATO SOILS

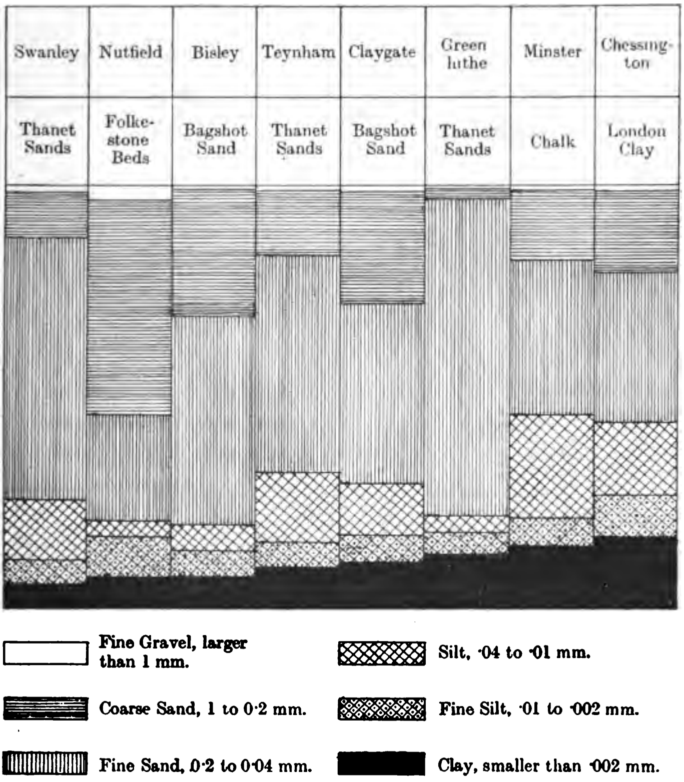


Fig. 23 *b*. Mechanical composition of soils well adapted for certain crops.

rotations were gradually introduced; liming and chalking were more carefully done; drainage was attended to; in the middle of the 19th century artificial manures

were introduced and tillages were improved; still more recently improved varieties and better seed have been available so that now 40 bushels are readily obtained by good farmers. Each improvement has consisted in removing some factor that was keeping down the yield to a certain level. But there still remain two sets of factors that cannot yet be controlled: the climate and the soil type. The difficulty is met by growing crops suited to the conditions, and this explains why certain crops tend to be grown on certain types of soil. In Fig. 23 are shown mechanical analyses of the soils on which in the south-east of England wheat and potatoes are found to do well.

Clay soils

There are two kinds of clay soils:

1. Those that arise through the presence of 20 per cent. or more of clay[1].

2. Those that owe their properties to the presence of considerable amounts of fine silt.

They are indistinguishable to the eye and have many properties in common, but they have this important difference: the "clay" can be flocculated by lime or by exposure to frost while the "fine silt" cannot. Hence the first group can be improved agriculturally by liming but not the second: indeed so far the "silty" clays have proved unmanageable.

The first group are the typical clays and are widely distributed in this country. The fine particles have certain properties which they impress on the whole soil: they are sticky when wet but set very hard when

[1] *I.e.*, particles less than ·002 mm. in diameter, see p. 16.

dry: they swell up on moistening and give out a little heat: they absorb heat and shrink on drying, and thus cause the large gaping cracks seen in dry weather on clay land. The fine particles also impede the movement of water so that the soil is very wet in wet weather but may suffer from drought in very dry weather.

If the soil is not limed and the drains and ditches are not well looked after the clay tends to go into the deflocculated form (p. 21) and then all the properties just described are intensified. The soil becomes difficult to cultivate owing to its persistent wetness: autumn sowing is difficult and sometimes impossible so that spring crops have to be substituted: the young plants only get through with difficulty and suffer badly in spring: a wet summer is bad and a wet harvest worse. Crops that ought to last a number of years, such as lucerne, only last two or three. If the land is laid down to grass the finer deep rooting grasses never get hold, the plants that survive being the surface rooting Bent grass (*Alopecurus pratensis*) which withers during dry weather and causes the burnt colour so common on poor clay pastures, the rushes, the coarse file-like *Aira caespitosa* and other plants specially adapted to wet places (Fig. 24).

The method of dealing with these soils is simple in principle but often difficult in practice: it consists in two parts: (1) arranging a way out for the water by means of a careful drainage scheme and clean ditches; (2) flocculating the clay and taking care that it does not get deflocculated. When this can be done clay soils become very suited for wheat, beans, and, in the southern half of England, mangolds,

but more especially they grow good grass so that both meadows and pastures are common. Considerable trouble arises from the fact that plant roots do not develope quickly and that crops do not readily ripen. Now we shall see later that phosphates have the special effects of inducing good root development

Fig. 24. Poor clay country. Roads wide but not all made up, hedges and gates not well kept.

and of hastening maturity, and we should therefore expect that phosphates would prove very beneficial on clay soils. Experiments all over the country show that this expectation is well founded: phosphates have a very considerable effect in improving the productiveness of clay soils.

The crop most generally suited for clay soil is grass, and therefore the agriculture usually centres

round live stock, dairying, etc. The manurial treatment is simple, lime and phosphates being the two chief requirements, and these can be conveniently supplied in dressings of basic slag. Where land is laid in for hay, nitrate of soda or sulphate of ammonia should be supplied in addition. The arable land must receive dung and periodical dressings of chalk or lime in addition to the phosphates. The treading of the horses tends to make a plough-sole which has periodically to be broken by means of a subsoiler, or, where steam cultivation is adopted, by putting a few extra long tines on the cultivator. But above all drains and ditches must be kept clean. Autumn work must always be got well forward so as to allow as much winter sowing as possible, winter corn and beans being more successful than spring corn. Late sowings only come to anything if the seed goes in well. Swedes and potatoes are not easy to grow and fallowing is necessary in order to keep the land clean and in good tilth; a bastard fallow may suffice, especially if it can be started early enough, but an occasional dead fallow lasting over the whole season is desirable and gives very good results, especially if the summer is hot and dry and the winter not too wet.

The second class of clays, the silty clays, are very truculent to deal with and no reliable method has yet been evolved. They can be found in the Lower Wealden beds in the district east of Horsham, on the Boulder Clay, the Coal Measures, etc.: they occur at Garforth in the West Riding and in numerous other places; everywhere they have a bad reputation which they thoroughly deserve. Lime and subsoiling have less effect than might be expected, and probably

the best treatment is to mole drain them and lay them down to grass: it is not worth while spending much on them as they do not respond well to treatment.

Sands

The chief agricultural properties of sandy soils arise from the fact that they are porous and readily allow the passage of water. Thus the water never accumulates and the soils only get waterlogged when they are underlain by a basin of clay: usually they suffer from drought in dry weather. In its passage the water carries with it much of the soluble matter: sometimes indeed so much that even weeds will not grow but only patches of moss which decay to a black acid substance entirely unsuited to most plants: such patches can be seen frequently on the Bagshot sands in Surrey.

Where there is a fair admixture of silt the movement of the water is retarded, and on moving aside the top two or three inches of soil the lower part is found to be quite moist even in dry weather. In these cases plants will grow well and a special type of treatment has been evolved to suit them.

In the first place the movement of the water has to be still further retarded, and regular additions of organic matter are therefore necessary. Secondly, lime has to be added regularly except in certain special cases where the soil lies at the foot of a long gradual slope and receives an underground drift of hard water from above. Lastly, fertilisers have to be added in small but frequent doses when the crop needs them. When these precautions are taken sandy soils will grow almost any crops, but they especially favour

the development of roots and tubers so that they are well adapted to potatoes, carrots, parsnips and nursery stock; further, they give good quality barley and useful but not large wheat crops. They are not suited for grass unless the water table happens to be only 3 or 4 feet from the surface in which case they may carry magnificent pasture: some of the very best Romney Marsh pastures are on sand. Otherwise the grass burns up badly in the summer time owing to lack of water.

Sandy soils tend very much to form pans, and care has to be taken to prevent this by occasionally using the subsoiler.

The management of sandy soils turns on the method by which the organic matter is to be added.

(1) If stable manure is available in large quantities a succession of heavy crops can be obtained, and recourse is then often had to market gardening: this is done on the sands near London, at Sandy in Bedfordshire, in parts of Essex and elsewhere. Where the market facilities are not quite so good potatoes can be grown on a dressing of 12–15 tons of stable manure, and a mixture of artificials rich in potash; a grain crop, two "seeds" crops, and another grain crop can then be grown on the residues and without further manure. The aftermath of the first seeds crop can be fed off with hay, cake, etc., while the aftermath of the second is ploughed in. The adoption of this method in Hertfordshire has enabled farmers to prosper on land which previously ruined its occupiers.

(2) The organic manure may be supplied through the agency of live stock. Sheep may be kept throughout the winter and folded on to green crops such as

rape, kale, winter barley, swedes, vetches, etc.; in addition they receive purchased feeding stuffs. The droppings from the animals fertilise the soil and return to it a considerable part of the substance of the crops and feeding stuffs supplied. Moreover the trampling of the animals has the further advantage of consolidating the land. The sheep have to be fattened and sold before summer or else removed to cooler pastures on higher ground, on chalk, etc. The same principles hold, with suitable modification, where bullocks are kept: home grown fodder is supplemented by purchased feeding stuffs and the bullocks are fattened and sold and the manure is carted out on to the land.

In both cases the organic matter added to the soil comes largely from the air, being built up by the crop under the influence of sunshine: in passing through the animal some is used up but much is excreted.

(3) A third method of adding organic matter to the soil consists in ploughing in a leafy crop: this is known as green manuring and may be adopted wherever live stock are not available. It is a very old method, but has come into considerable prominence since Schultz in 1855 enormously improved his estate of barren sand at Lupitz at very small cost by growing lupins fertilised with potash, phosphates and lime and then ploughing them in. The lupins, being leguminous plants, fixed nitrogen from the air and thus increased the stock of nitrogenous organic matter in the soil: indeed they acted like a dressing of farmyard manure. Various modifications have come into use: in this country mustard is sometimes used for the purpose

and is found on the sandy soil at Woburn to give better results than vetches, although it is a non-leguminous crop: on the heavier soil at Rothamsted, however, it gives poorer results:

Yield of wheat, bushels per acre

	At Woburn[1]	At Rothamsted[2]
After vetches	15·1	36·25
„ crimson clover ..	—	28·5
„ mustard	25·1	25·8
„ rape	20·4	22·6
No green crop	10·1	17·5

Green manuring has not been extensively adopted in this country because farmers prefer to feed their crops to stock and so get fat animals as well as manure. But it seems probable that more use might with advantage be made of the system and that the organic manure added to the soil should not be limited by the number of animals the farmer may find it convenient to keep.

Whatever the system of agriculture, it is desirable to crop as frequently as possible because sandy soils lose a great deal of their fertilising constituents if left bare and exposed to the rain. The cultivations must also be thorough to keep down weeds: no soils are so prone to be smothered with weeds as are sands.

The manuring has to be decided by the crop: reference has already been made to the paramount importance of organic matter and of lime: potash is wanted for many crops, especially potatoes, while phosphates are usually needed to prevent rankness in the grain crops taken after green crops have been

[1] J. A. Voelcker's experiments, Four years: 1906, 1908, 1910, 1912.

[2] Three years: 1907, 1910, 1912.

fed off and also to secure the maximum feeding value of the green crops themselves.

Soluble manures must only be added in small quantities at a time because of the ease with which they are washed out. Sandy soils have less capacity than clays for absorbing soluble substances: this can be demonstrated by the following experiment. Dissolve 0·3 grams of superphosphate, dilute to 500 c.c. and divide into two lots of 250 c.c. To one add 50 grams of a light sandy soil, and to the other 50 grams of a heavy clay soil, shake both solutions well for 3 minutes, allow to settle for 3 minutes, shake, and settle again. After 15 minutes filter. To 50 c.c. of each filtrate add 10 c.c. of ammonium molybdate solution (p. 200). Much more precipitate is obtained from the sand than from the clay.

A similar experiment with a weak solution of ammonium sulphate (2·5 grams per litre) in place of superphosphate shows that clay also absorbs ammonia more completely than sand. In this case 25 c.c. of the filtrates are distilled with caustic soda and the ammonia in the distillates determined by titration.

A third experiment with burnt sugar solution proves that soluble organic matter, like ammonia and phosphates, is absorbed to a greater extent by clay than by sand.

Sandy soils and light soils generally are very attractive because they are more under control than most others. No matter how wet the season they can be worked. An intelligent man may get two crops in the year from part of the land: after early potatoes, for example, he may take cabbage, sprouts, or sprouting broccoli. Strawberries can be successfully

grown and many other valuable crops. No rigid rotation can be adopted: there must always be a certain amount of cross-cropping. Few soils, however, are so entirely dependent on the skill and intelligence of the farmer. Some of the best farms in England are to be found on the sands: they are managed on sound lines, well manured, kept free from weeds, and made to yield heavy crops: labour-saving devices are introduced and the skilled hands are well paid. On the other hand bad management speedily ruins the land and the farmer: docks, bindweed, sorrel, corn marigold, spurrey, and a host of other weeds soon come in and before long the land is useless.

Loams

Loams come in between sands and clays and can only be defined as soils which are not as heavy as clays and not as light as sands. Usually they contain not more than 10 to 15 per cent. of clay and not more than 20 per cent. of coarse sand; they are chiefly made up of intermediate material. All shades of loams exist, from the light loams which some would call sands, to the heavy loams which can also be called clays.

Loams are by far the most fertile soils in the country; instances are to be found in the brick earths of East Kent and near Chichester, the alluvials of some of the famous vales and of the Evesham district, the famous Carse of Gowrie (locally called a clay) and many others. Practically any crops will grow—climate permitting, of course—and the cultivator may adopt any scheme of management he finds most profitable.

Usually speaking bullocks or dairy cows play the

central part on the heavy loams and sheep on the light loams, the animals in both cases being required to act as manure-making machines, and also to convert the less portable products such as straw, roots, etc., into portable and saleable meat. As an illustration of heavy land arable farming: in parts of Oxfordshire the land is farmed roughly on a four course shift of clover, wheat, mangolds (with some swedes), oats (and some barley)—swedes and barley being less suited than mangolds, and oats for heavy land are not so widely grown. In the second period beans are taken in place of clover (which will not succeed if attempted too often) and are well dunged as they are a profitable crop. There is a good deal of grass. Dairy cattle are kept by some: others buy in yearling stores at a low price and keep them till they are worth considerably more, then sell them out to be fattened elsewhere. On the light land the traditional rotation is clover, wheat, swedes and barley: the swedes and the aftermath of clover are fed off by sheep which also receive cake, etc., the wheat and barley can be sold, but there are many variants and many farmers indeed have no fixed rotation but grow those crops that promise to be profitable at the time. Among the crops introduced in the rotation in the eastern counties are peas, sainfoin and lucerne: elsewhere the number of crops varies and there is taken one green or root crop to two grain crops. It is not our business to discuss the rotations in detail but only to consider their effects on the soil. The root crop may be either swedes, kohl-rabi, cole, mangolds, turnips or potatoes as convenience requires: in any case its effect on the soil is to afford an opportunity for exterminating

weeds, and the frequency with which it is taken is determined in part by this consideration.

Now light soils are very prone to weeds, in particular to charlock (*Brassica sinapis*). Heavy soils suffer less, but still are liable to docks, thistles, etc. Charlock can be kept down by spraying[1], the others cannot. Sometimes the land will keep clean for four and sometimes for five years: in that case two corn crops can be taken in succession and a winter oat crop inserted between the wheat and the roots: or the clover may be replaced by a mixture of clovers and grasses which can be left for a period of years. Again, the root crop may be eaten in the field by sheep wherever the soil is not too wet, and the soil then receives not only the fertilising constituents derived from the crop but also those derived from the added feeding stuffs. This furnishes an extremely useful method of fertilising the soil for the next crop: it reduces the losses of manure to a minimum (see p. 153), it saves cartage of manure, and it enables rapidly grown catch crops to furnish their quota to the organic matter of the soil. But the method is not feasible in heavy soils because sheep "poach" the land too badly and ruin the tilth; here therefore the roots have to be drawn off, farmyard manure has to be made and carried out on to the land.

A third effect of the root crop is that it affords the best means we have now for fallowing the land. In old days bare fallows were adopted: now they are uneconomical. But it appears that bare fallows do have a remarkable effect on the crop especially

[1] A 3 per cent. solution of copper sulphate sprayed in early spring at the rate of 50 gallons per acre.

in enabling a more vigorous start to be made. Now the root crop is usually taken after a corn crop, so that the land is well cultivated but uncropped from harvest—say October—to the time of sowing; cultivation continues, and the land is almost uncropped till June, when the root crop begins to grow; indeed cultivation sometimes goes on longer. The grain crops, on the other hand, follow continuously: the barley is seeded with clover so that the land is not even ploughed between these two crops: the clover is ploughed in just before the wheat is sown, and if winter oats follow, this crop in turn is sown just after the wheat is harvested. Only when the root crop comes round is there much opportunity for cultivating the soil well and giving it the benefits of the fallow effect. There are of course exceptions: in forward districts the harvest may come so early that steam tackle can at once be put on to the land and a bastard fallow given before the next corn crop: it is then not necessary to give a rest between the corn and the roots but a series of catch crops can be taken.

The root crop also gives a good opportunity for deep ploughing or subsoiling.

So important is the root crop that special care is taken to secure a good seed bed and to supply appropriate manures. Experiments on the best way of preparing the bed are badly needed: there is great diversity of opinion among good practical men on the subject. Numerous manurial experiments have been made, however, and have demonstrated the need of adding lime wherever finger and toe (*Plasmodiophora brassica*) is common, of supplying phosphates, and on light soils potash as well.

The effect of the clover or seeds mixture on the soil is that it adds nitrogenous organic matter to the soil. Experiments have shown that crop residues of this sort not only increase the fertility of the soil by the additional nitrogen thus introduced, but they are particularly valuable in reducing the harmful effects of bad weather on the soil, and steadying the fluctuations of soil productiveness produced by bad weather. This is well illustrated by a comparison of the wheat crop taken after clover (supplemented by artificial fertilisers) on the Agdell Field at Rothamsted, with that on the Broadbalk Field where no green crop is ever ploughed in but where a liberal dressing of artificials is given. On an average the Agdell plot gives a yield of 34¾ bushels against 29½ on Broadbalk, and it is a much steadier crop. It has only twice fallen below 25 bushels, once in 1867 and again in that notorious year of disaster 1879, when it got as far down as 13½ bushels. But the Broadbalk plot which has never been green manured fluctuates to a much greater extent; the yield has frequently dropped below 25 bushels (Table IV).

TABLE IV. *Steadying effect of crop residues on yield of wheat*

	After clover ploughed in; complete artificials	After previous wheat crop; complete artificials
Average of all	35	30 bushels
Highest yield, 1863 ..	46	56
Low yields, 1871	25	13½
1875	31	11
1879	13	5
1903	28	24

It is a common practice in the North of England and Scotland to leave the seeds mixture for 3, 4 or more years.

The clover crop is so necessary that great pains must be taken to secure it. If there is any difficulty (and there often is) a dressing of lime must be given: if this fails a dressing of sulphate of potash (2 cwt. per acre) should be tried and if this still fails a fresh variety of clover ought to be grown.

The lighter loams tend to be used for special crops like fruit, market garden and nursery produce, malting barley, etc., and their management then requires very great skill and intelligence. Some have always been used for these purposes, such as the Thanet Beds of East Kent, but many of them, like the sands, were formerly held in but little repute, and have only during the past 30 or 40 years come into favour. The New Red Sandstone of Somerset affords instances of light loams not very suited for ordinary agricultural purposes, but well adapted to fruit, market gardening, etc., while the light loams round Porlock are famous as the source from which many prize samples of barley have come to the Brewers' Exhibition.

Chalk soils

Chalk soils are usually very light loams but they require special attention because of their great economic importance. Like all light soils they are liable to drought but they possess the unfortunate property of drying to hard steely fragments unless they are worked to a good tilth at the proper time: they therefore require special care in cultivation. Organic matter

is very necessary for them, and sheep therefore play a large part in chalk districts. Further, during frosty weather they become so puffed up and lightened that the young crops are sometimes almost forced out of the ground: rolling is therefore necessary in the spring not only on the grass but also on the arable land.

Leguminous crops are especially valuable on the chalk by reason of the organic matter they introduce, and among the most useful is sainfoin; lucerne also grows well and is grown especially in the drier regions.

Chalk soils are highly favourable to plant and animal life, but this has its disadvantages: they carry a very varied flora and care is needed to keep down weeds, especially charlock. Swedes and the brassica tribe generally are liable to attack by the turnip fly (*Phyllotreta nemorum*) and all crops to damage by wireworm.

The central feature of the manuring is the folding of sheep: superphosphate is needed for the roots, and potash manures for the clover or seeds ley. On the grass land basic slag often effects remarkable improvements especially in the wet districts or where the top inch or so of soil has lost its calcium carbonate.

Summary

In order to get the best out of the land an inspection must be made to see what is likely to be its chief defects, in other words, what will constitute the limiting factors. There may be insufficient water or excess of water, insufficient depth of soil, insufficient of any of the proper constituents: (*a*) of clay, when the soil will not hold together but will blow about; (*b*) of calcium carbonate, when the tilth will be poor and

the soil sour as shown by the presence of sorrel, the failure of clover, and by poor growth generally; (*c*) of organic matter, when the tilth will be unsatisfactory; (*d*) of various nutrient substances.

The defect may arise from the fault of the soil itself or of its situation.

Any defect of this kind will set a limit beyond which the crop cannot be increased. To remove the defect may be the landlord's business rather than the tenant's, but it is useless to try and force the crop beyond the limit thus set. Once the defect is removed, however, better crops can be obtained.

The central features of management in cropping land up to its full capacity are:

Crops and varieties are selected that are specially suited to the conditions.

Sufficient lime or chalk is added. The land is periodically subsoiled or ploughed deep. Every effort is made to keep up the supply of nitrogenous organic matter in the soil: leguminous crops are grown: "seeds" are left for two or three years and sometimes crops are grown simply to be ploughed in. The supply of plant nutrients is kept up by the addition of appropriate artificial manures and by supplying imported foods to sheep on the land and to cattle in the yards, when much of the fertilising constituents are excreted and thus get on to the land.

Wherever the soil is not too wet or sticky the rotation is so arranged as always to provide a crop that sheep can eat. Part of the land is kept in permanent pasture and thus becomes richer in nitrogenous organic matter. The necessary mineral food is added in the form of phosphates and potash salts.

PART III

FERTILISERS

CHAPTER VII

THE NITROGENOUS FERTILISERS

In attempting to satisfy the various fertility requirements discussed in the previous chapter it becomes necessary to increase the amount of plant nutrients in the soil and to this end various substances are added which are known as fertilisers and manures. The distinction between the two terms is not very sharp, but generally a fertiliser is a concentrated substance imported on to the farm from a foreign country or a factory, and therefore is frequently called an artificial fertiliser, while a manure is a more bulky material either produced on the farm or closely related to farm products.

The substances thus added to the soil are compounds of nitrogen, phosphorus and potassium: also organic matter and lime or chalk. In order to study their effect on the soil a series of pot experiments should be started: 10 inch flower pots are sufficiently good for ordinary purposes but for finer work Doulton's glazed pots must be used (Fig. 1). The soil has to

be carefully mixed to ensure uniformity and if it is heavy 10 to 20 per cent. of sand must be added. The series should contain pots treated as follows: (1) unmanured; (2) and (3) 0·01 and 0·05 per cent. respectively of nitrate of soda; (4) 0·1 per cent. superphosphate; (5) 0·1 per cent. sulphate of potash; and three or four containing combinations of these quantities; other pots should be supplied with sulphate of ammonia in place of nitrate of soda, and bone meal and basic slag in place of superphosphate. If a glass house is available tomatoes are a good crop for experiment; or at colder seasons mustard. For outdoor work rye, wheat or mustard do well.

Two types of nitrogenous fertilisers are in common use: nitrates which are ready and ammonium salts which are almost ready for immediate use by the plant and are therefore quick acting, and certain organic compounds which have to undergo decomposition in the soil. The first only are dealt with in this chapter.

Nitrates

Three nitrates are now available as fertilisers: the nitrates of soda, of potash and of lime, and experiments are being made with a fourth, nitrate of ammonia, but of these the commonest is nitrate of soda ($NaNO_3$). This substance occurs in the rainless regions of Tarapaca and Antofagasta in the north of Chile, where it forms deposits near the surface of the soil. The deposits occur in detached areas stretching over a wide range and in spite of the large annual consumption—now nearly 2,500,000 tons—there still seems a vast supply for the

future. It is not known how the deposits originated: there is little doubt that they were once under water, but there is nothing to show how so much nitrate came to accumulate in one district: only traces occur in ordinary sea-water. The crude nitrate is excavated by a process of trenching, it is then crushed, purified by recrystallisation and put up in bags for the market.

The commercial product is not quite pure, but it is guaranteed to contain 95 per cent. of nitrate of soda and often contains even more.

Nitrate of soda is very quick acting as a fertiliser and can be taken up immediately by the plant. It finds application in two cases: (1) in case of emergency, when the plant is suffering through the attack of a pest, or in cold wet weather; (2) in ordinary practice as a top dressing for the crop. It causes increases of practically all crops in England and the dressing applied varies from 1 cwt. per acre, suitable for wheat in spring or grass laid in for hay, to 10 cwt. per acre used on the valuable early cabbage and broccoli crops in Cornwall. In other countries, however, such returns are not always obtained: in parts of Australia and New Zealand phosphates are the limiting factor: in Western Canada water appears to be; in none of these cases do nitrates give the same high returns as in this country.

Besides causing increased growth nitrate of soda produces certain qualitative effects on the crop. It imparts darker green colour and greater size to the leaf: in the case of straw crops it may so enlarge the leaf and the head that the straw is unable to carry the weight in wet weather, and the crop becomes laid. Applied in excess it tends to thin the cell walls,

making them more readily penetrated by fungoid pests, and it also appears to alter the composition of the sap in some way so that the fungi develope more readily than usual.

In addition to these effects on the plant another effect is produced on the soil. The whole of the nitrate of soda is not retained by the plant but a decomposition takes place, the nitrate part being retained while some of the soda part remains in the soil as sodium bicarbonate. This reacts on some of the potassium compounds in the soil, liberating a certain amount of potash which then becomes available for the plant; this has been demonstrated by actual field experiments at Rothamsted, and is also illustrated by the experiment on p. 125. But the bicarbonate also acts on the clay, converting it into the sticky deflocculated state, and on a heavy soil this action becomes rather serious, causing much damage to the tilth. A suitable remedy is found in dressings of lime or addition of sulphate of ammonia to the nitrate. The student who is interested in the history of the subject will find that, in the old papers, nitrate of soda is sometimes called a "scourge," and some of the older farmers still retain a dislike to it. This idea probably arose partly from its harmful effect on the texture of a heavy soil and partly from its effect on hay land. It encourages a very good growth of top grasses and may be used with great advantage whenever hay is sold. But the heavy crop naturally draws on the soil phosphates, and unless these are replenished at the same time the soil becomes impoverished and the crop ultimately falls off in quantity, while weeds and poor grasses appear and bring down the quality. Grass land should

never as a regular course be fertilised with nitrate only, but should periodically receive the other necessary fertilisers.

Nitrate of soda readily washes out of the soil and must therefore not be applied until it is needed. It is best put on as a top dressing when the plant is up: when this course is adopted the loss in a wet season is reduced to a minimum: there is the further advantage that the nitrate of soda does not come in contact with the superphosphate (which is drilled with or before the seed): these two fertilisers do not mix well although if put on at once the mixture can be used where labour is scarce. Heavy dressings such as are used in market gardens should be applied in two or three lots and not all at once.

The ordinary nitrate of soda of commerce contains 15·5 per cent. nitrogen and its usual price is about £11 per ton f.o.r.[1]; each per cent. or "unit[2]" of nitrogen therefore costs 14*s.* 8*d.*, and each pound of nitrogen costs 8*d.*

Nitrate of potash (KNO_3).

This substance is dearer than a mixture of nitrate of soda and sulphate of potash supplying the same ingredients, and therefore it is not used in this country. But being much less bulky than the mixture it finds considerable application in countries where valuable crops are raised and freights are high: thus it is used in the Canary Islands and elsewhere under similar conditions.

[1] F.o.r. = free on rail. Prices delivered to the buyer's station may average about 10*s.* per ton extra.

[2] See p. 177.

Commercial nitrate of potash contains nearly 14 per cent. of nitrogen.

Nitrate of lime

Of recent years a considerable quantity of nitrate of lime has been manufactured and put on the market for use as a fertiliser. The industry is carried on at Notodden in Norway and at Niagara where abundance of cheap water power occurs, and the process consists in burning air in an extremely hot flame—probably 3000°–3500° C.—by means of a powerful electric arc in a small chamber: the products are then made to react with lime.

In ordinary circumstances nitrogen is not combustible and the mixture of nitrogen and oxygen in the air is not inflammable, but at this very high temperature the nitrogen burns and unites with the oxygen to form oxides, chiefly nitric oxide. The gases are cooled, and mixed with air, when a higher oxide, nitrogen peroxide, is formed; they are then drawn with fans through towers packed with broken quartz down which water trickles, and become converted into a dilute mixture of nitrous and nitric acids and finally into nitric acid. This is then neutralised with limestone and the solution on evaporation yields calcium nitrate[1].

The first samples to be placed on the market were not easy to use as they so readily absorbed moisture and became converted into a sticky pasty mass, but this difficulty is gradually being overcome, and recent samples show considerable improvement.

[1] For details of the process of manufacture see paper by Eyde, *Journal of the Royal Society of Arts*, 1909, vol. LVII. p. 568.

As a fertiliser calcium nitrate closely resembles sodium nitrate, but it appears to be free from the disadvantage of making heavy soils sticky. Further experience is needed before any very definite statements can be made, but so far as present knowledge goes nitrate of lime is a very promising addition to the list of nitrogenous manures.

Sulphate of ammonia

This substance is manufactured from coal. The potential supply is enormous: a ton of coal contains on an average some 25 lbs. of nitrogen, which yields just over 1 cwt. of sulphate of ammonia. Unfortunately most of our coal is burnt under such conditions that the nitrogen is lost, but in certain industries, especially in the manufacture of coal gas, of producer gas, in coking ovens, etc., special recovery methods are used and sulphate of ammonia is obtained as a by-product[1]. The world's output in 1912 was well over one million tons, this being nearly three times the quantity produced in 1900. The process is not costly and it seems capable of considerable extension. Peat also contains nitrogen and is being tested as a source of ammonia: methods have been devised by Mond, Frank, Caro and others.

In its general action sulphate of ammonia differs but little from nitrate of soda, and the choice between them is mainly one of price and convenience. It possesses, however, certain characteristic features which sometimes assume considerable importance.

When applied to the soil it reacts with the calcium

[1] For details of the recovery methods see art. "Ammonia" in Thorpe's *Dictionary of Applied Chemistry*.

carbonate, giving rise to calcium sulphate and ammonium carbonate. The calcium sulphate washes out in the drainage-water, but the ammonium carbonate does not, being absorbed by some of the reactive constituents of the soil (p. 21). The ammonium carbonate becomes nitrified by bacterial action, and presumably is changed to calcium nitrate through interaction with more calcium carbonate. Thus the complete change requires that one molecule of ammonium sulphate should react with two molecules of calcium carbonate thus:

$$(NH_4)_2SO_4 + 2CaCO_3 + 8O_2 \\ = CaSO_4 + Ca(NO_3)_2 + 4H_2O + 2CO_2.$$

On this basis a dressing of 132 lbs. of ammonium sulphate (*i.e.*, one molecular weight) involves the removal from the soil of 200 lbs. of calcium carbonate. Now actual analyses at Rothamsted show that only one half of this quantity, *i.e.*, only 100 lbs., is removed, and further experiment has shown that the calcium nitrate is not wholly retained by the plant but the calcium is left in the soil and re-converted into carbonate[1].

There still remains, however, a loss of 100 lbs. of calcium carbonate for each 132 lbs. of ammonium sulphate applied, and on soils deficient in lime this becomes very serious for two reasons: the lime is greatly needed for other purposes; and in its absence ammonium sulphate leaves an acid residue in the soil, the ammonium portion being more completely taken by plants than the rest. Now most agricultural plants will not tolerate this acidity, and in extreme cases completely refuse to grow. This remarkable

[1] Hall and Miller, *Proc. Roy. Soc.*, 1905, 77 B, 1–32.

action was first observed by Dr Wheeler at the Rhode Island Experiment Station in 1890[1] and was investigated in an important series of experiments which showed that the trouble could be completely remedied by dressings of lime. A few years later the same phenomenon appeared at the Woburn Experimental Farm and has been fully described by Dr Voelcker[2]; there also lime was found to be the proper remedy.

Thus sulphate of ammonia tends to make the soil acid, and therefore physiologically unsuited for plants, while, as already pointed out, nitrate of soda tends to make it alkaline and therefore physically unsuited to them. A mixture of the two fertilisers produces no such effects, as each neutralises the other.

Sulphate of ammonia, unlike nitrate of soda, is completely absorbed by the soil and shows no tendency to wash out. This can be demonstrated by packing 50 grams of soil (preferably a loam) on to a funnel, moistening with water and then pouring on 100 c.c. of 1 per cent. ammonium sulphate solution. Test the filtrate for calcium, for sulphate, and for ammonia. The two former occur in quantity, but the ammonia is reduced in amount. Now repeat the experiment with a fresh lot of soil and a 1 per cent. sodium nitrate solution. The nitrate shows no diminution in amount[3] but some action nevertheless goes on and calcium occurs in the solution. In consequence ammonium sulphate is much in favour in tropical countries and is used in the West Indies for the sugar cane. Of

[1] Rhode Island Exp. Station, *3rd Annual Report*, 1891, p. 53; *4th Report*, *et seq.*

[2] *Journ. Roy. Agric. Soc.*, 1897, p. 287; and subsequent years.

[3] A suitable test is given on p. 195.

course as soon as it has become nitrified it is liable to sink to greater depths, but in an acid soil, or wherever nitrification is not very active, it remains in the surface layers. Here it encourages a surface rooted vegetation, and for this reason it is used on lawns where only the fine shallow rooting grasses are desired.

This tendency to remain in the surface layers has sometimes given sulphate of ammonia an advantage over nitrate of soda on sandy soils not deficient in lime[1].

Commercial sulphate of ammonia contains about 20 per cent. of nitrogen; it is the most concentrated of all these manures. Its normal price is about £13 per ton f.o.r.: 1 per cent. per ton (or 1 unit) therefore costs 13*s*. and a pound of nitrogen in this form costs 7*d*.

Calcium cyanamide or Nitrolim[2]

This fertiliser, like calcium nitrate, is made from air and limestone. There are two stages in the manufacture: first a mixture of calcium carbonate and carbon is heated in an electric furnace to a high temperature, when calcium carbide (CaC_2) is formed; this is then heated in a stream of nitrogen and gives calcium cyanamide ($CaCN_2$). It was first made at Piano d'Orte in Italy, but now it is produced at Odda in Norway, Alby in Sweden, at Niagara and elsewhere where great supplies of water power are available. Calcium cyanamide is not soluble in water and is not a direct plant nutrient. But some of the soil bacteria have the remarkable power of decomposing it with formation of calcium carbonate and ammonia,

[1] An instance is quoted in *Bied. Centr.*, 1908, XXXVII. 585.

[2] "Kalkstickstoff," in the German papers. There is another substance, not dissimilar, known as "Stickstoffkalk," which, however, has only a small local sale.

which is then utilised in the usual way. In consequence of the need for this preliminary change calcium cyanamide is somewhat slower in action at Rothamsted than sulphate of ammonia. Being insoluble it is not at all likely to be washed out from the soil, while the calcium carbonate formed on decomposition is distinctly valuable. It is best applied at or before the time of sowing so that decomposition may proceed before the plant has grown; when used as a top dressing some samples have produced harmful effects, but it does not appear that these invariably set in.

Comparison of these nitrogenous fertilisers

Table V gives the results obtained at Rothamsted in comparative experiments with these various fertilisers:

TABLE V. *Effect of various nitrogenous manures on different crops. Rothamsted: yield per acre* 1909–1912

	Barley, 1909		Wheat, 1910		Mangolds, 1911	Mangolds, 1912
	Little Hoos Grain	Little Hoos Straw	Little Hoos Grain	Little Hoos Straw	Little Hoos	L. Knott Wood
	bush.	lbs.	bush.	lbs.	tons	tons
No nitrogen	28·7	2619	15·4	1526	9·8	11·5
Nitrate of soda	48·1	3882	27·0	3760	15·4	18·4
Sulphate of ammonia	49·1	3517	24·6	2964	11·8	—
Cyanamide	45·2	3976	22·4	2343	11·1	—
Nitrate of lime	46·2	4449	20·6	3618	12·7	18·4

In 15 experiments at Aberdeen[1] the nitrolim proved equal to nitrate of soda or sulphate of ammonia,

[1] Aberdeen and North of Scotland College, *Bulletin* No. 13, 1909. *Trans. Highland and Agric. Society*, 1909, 122–134.

while nitrate of lime was rather better, but owing to its hygroscopic nature it was less easy to handle. In all these experiments each substance is tested on one plot only and in all such cases results can only be relied upon to within 10 per cent. in any one season, or some 5 per cent. over several seasons. For finer work it is necessary to repeat the plots 4 or 5 times in the same field each year, and to ascertain from the results exactly what is the error of experiment. The method of doing this is described by Wood and Stratton in the *Journ. Agric. Science*, vol. III. p. 107, a paper which the student should read.

CHAPTER VIII

PHOSPHATES

PRACTICALLY all of the clay lands of the country and many of the other soils stand in need of phosphates, and the higher the standard of farming the greater is the amount required. There are three main sources from which supplies are drawn: bones, superphosphate, and basic slag.

Bones

Bones have long been applied as manure in isolated parts of the country, but they were not commonly used until the beginning of the 19th century. Such remarkable results were then obtained in certain districts, *e.g.*, in Cheshire, that the demand became very great, and the rather large accumulations of the past in various parts of the world had to be drawn

upon to satisfy it. The demand still continues; the butcher shops, meat markets and marine store dealers of the great cities are ransacked to keep up the supply. In modern practice the bones are sent to the works, put on to a perforated band and sorted; clean shank bones are picked out for cutlery, hard bones for glue making and the remainder for crushed bone: the separate batches are steamed at low pressure (15–20 lbs.) to remove fat, nowadays a valuable commercial product. In some works the bones are degreased with benzene, and this process is more efficient than steam, so that the residual bone meal is richer in nitrogen and in phosphate.

Bone meal. The bones intended for this purpose are then crushed and sorted into half inch bones, quarter inch bones and bone meal.

Steamed bone flour. The bones intended for glue, and the ends of the cutlery bones, are crushed and again steamed but this time at a higher pressure (50 lbs.), when most of the nitrogenous constituents are extracted as gelatine or glue. The residue can now be got into a very fine state of division and is sold as steamed bone flour.

Dissolved or vitriolised bones. These are made by treating bones with sufficient sulphuric acid to dissolve about half of the phosphate. The product is usually somewhat sticky, and has not the finish of a well made superphosphate. The following table gives the composition of various bone manures, but as the material is very variable the figures are to be considered as approximate only. Raw bones are still used in the Wolds of Yorkshire and in certain other districts but not generally elsewhere.

	Nitrogen	Equivalent to ammonia	P_2O_5	Equivalent to tricalcic phosphate
Raw English bones	5	6	22	48
Bone meal	3·5–5	5–6	20–25	43–55
Steamed bone flour	1–2	1–2·5	25–32	55–69
Dissolved bones	2–3	2·3–3·8	15–16	33–35

Bone meal usually acts best on soil rich in humus or soils lacking in lime and is not very satisfactory on calcareous soils. At Rothamsted it gave good returns for spring wheat, barley and swedes, and also at Saxmundham, but in other experiments it has not proved as useful as basic slag or superphosphate.

Steamed bone flour contains less nitrogen, but so far as the phosphate is concerned it has the advantage that it is very finely divided and can readily be distributed. It has good results on light alluvial loams.

Dissolved bones resemble superphosphate in their action but are on the whole less satisfactory.

Superphosphate

On May 23rd, 1842, Lawes patented his process for manufacturing superphosphate and thus founded the artificial fertiliser industry which has since attained enormous dimensions. The principle of the process is very simple: rock phosphates (themselves of no great fertilising value in this country) are treated with sulphuric acid so as to convert the tricalcic phosphate $Ca_3(PO_4)_2$ into the more soluble compound to which the formula $Ca(H_2PO_4)_2$ is assigned: in addition calcium

sulphate is formed. The following is the usual expression of the reaction:

$$Ca_3(PO_4)_2 + 2H_2SO_4 = 2CaSO_4 + Ca(H_2PO_4)_2.$$

The mixture of calcium sulphate and monocalcic phosphate constitutes the superphosphate. No separation is attempted, and the calcium sulphate or gypsum is left in: it not only does no harm but has itself some fertilising value and indeed was much used in the past: it also serves to get the superphosphate into a dry condition because it absorbs water very completely. The process has attained a considerable degree of perfection, and allows of the production of a high grade product, finely powdered and dry, free from many of the defects of the older samples. The world's annual production is about 10 million tons.

The rock phosphate comes largely from Northern Africa and it contains other substances besides calcium phosphate: the resulting superphosphate is therefore not entirely constituted as shown in the equation. The rock sometimes contains calcium carbonate, in which case an additional proportion of calcium sulphate is present.

It has been found convenient to standardise the various grades of superphosphate and sell them on a definite basis. The amount of soluble phosphate is determined by analysis as P_2O_5 and the figure is then calculated as tricalcic phosphate. Thus the ordinary grade contains about 12 per cent. P_2O_5 soluble in water; this figure is then multiplied by 2·18 to convert it into tricalcic phosphate $Ca_3(PO_4)_2$. Both figures are conventional in that superphosphate contains neither P_2O_5 nor $Ca_3(PO_4)_2$, but either figure

does very well to express the amount of phosphate soluble in water. The following grades are now obtainable:

	Usual price f.o.r.	Price per unit of phosphate	Price per unit of P_2O_5
"26 p.c. soluble" equivalent to 11·8 p.c. P_2O_5	48*s.*	1*s.* 10*d.*	4*s.*
"30 p.c. soluble" ,, 13·6 ,,	52*s.*	1*s.* 9*d.*	3*s.* 10*d.*
"35 p.c. soluble" ,, 16·0 ,,	60*s.* 6*d.*	1*s.* 9*d.*	3*s.* 10*d.*

The student must realise very clearly that the expression "30 per cent. super" does not indicate the presence of 30 per cent. of anything in the manure itself. It simply means that the soluble phosphate present would amount to 30 per cent. *if it were there as tricalcic phosphate.* But it is not, and the only justification for this rather cumbersome method of expression is that all manures are worked out on the same basis, and that everybody has got used to it. The more concentrated grades save freight; the others supply a larger amount of gypsum which under some circumstances has distinct manurial value.

Superphosphate has two remarkable effects on the crop: it favours root development in the early stages of plant growth, and it hastens maturity in the later stages. It is specially useful for swedes and turnips, and gives returns even when the soil seems rich in phosphates. Fig. 25 shows the results obtained at Rothamsted: unmanured turnips failed to swell and remained like radishes, turnips manured with superphosphate and potash swelled to a considerable size even without nitrogenous manure, while when this was added still further growth was obtained.

After a wet winter a dressing of 3 cwt. of super may considerably assist the young winter corn to form

roots. Nitrate of soda or sulphate of ammonia should be given at the same time.

Its effect on maturity is well seen on the barley plots. Wherever phosphates are withheld the crop

Plot 1 3 5

Fig. 25. Effect of fertilisers on swedes. (Agdell field, Rothamsted, 1912.)

Plot 1. Complete manure—phosphates, potash and nitrogen compounds.

,, 3. Incomplete manure—phosphates and potash but no nitrogen compounds.

,, 5. No manure.

ripens badly: where they are supplied it ripens well. Indeed cases are on record elsewhere where the ripening has gone on too quickly, so that the crop has suffered in consequence.

At Rothamsted the barley on the permanent

plots stands greatly in need of phosphates: the results are plotted in Fig. 26.

Phosphates also increase the feeding value of fodder crops and for this reason must be liberally used wherever

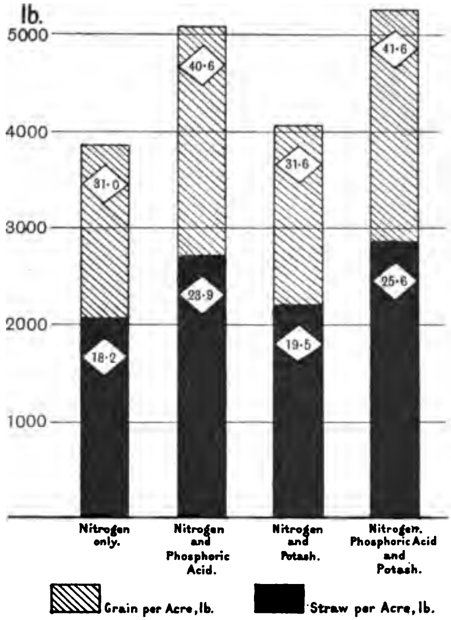


Fig. 26. Effect of phosphates and of potash on the yield of barley. (Hoosfield, Rothamsted.) (Average 60 years, 1852–1911.)

The columns represent total produce per acre while the figures in the diamond spaces give bushels of grain and cwts. of straw per acre.

recourse is had to folding or where many head of stock are kept. Addition of superphosphate to the seeds ley often leads to improvement in the sheep grazing the aftermath.

In horticultural practice superphosphate proves

very valuable for inducing hard growth in plants that are becoming too sappy.

Even small dressings have produced marked all-round improvement on soil very deficient in phosphates. The most striking examples are found in Australia and have been investigated at the Roseworthy Agricultural College[1]; good instances also occur in Cardiganshire Striking effects are also produced in the Fens.

Superphosphate is soluble in water but it is rapidly precipitated in the soil and only very small quantities are found in the drainage-water: practically the whole of the superphosphate added to the Rothamsted soils during the past 60 years and not taken by the crop still remains in the soil. It is sometimes described as an acid manure but the statement is misleading: there is no evidence that it causes the soil to become acid: the Broadbalk plot manured with superphosphate does not lose its lime any more quickly than the corresponding plot without superphosphate. It has no bad effect on the texture of the soil, on the contrary it not infrequently causes an improvement.

Basic slag (formerly called basic cinder, Thomas' phosphate powder, etc.)

Most iron ores contain a certain amount of phosphorus which has to be removed before a satisfactory steel can be produced. Two types of processes are in use for this purpose: basic processes and acid processes. There are two basic processes. In one the iron is melted in a Bessemer converter lined with lime and magnesia, and a stream of air is blown through to convert the phosphorus into an oxide which then

[1] See especially *4th Report*, 1909–11.

unites with the material of the lining and forms basic slag. The other and more recent is known as the basic open hearth process in which, as the name indicates, the iron is melted in an open furnace and not in the converter. Both processes yield basic slags which are widely used as fertilisers. The acid open hearth processes are of less agricultural interest since the slags produced are not commonly on the market and are not recognised phosphatic fertilisers, although they contain considerable quantities of phosphate.

When basic slag was first obtained in the Bessemer converters in 1879 its fertilising properties were not recognised; not till John Wrightson in 1884 and 1885 made his field experiments at Ferryhill and at Downton, and Paul Wagner in 1885 began his systematic pot experiments at Darmstadt, were agriculturists aware of its value. It gradually came into use and within 4 or 5 years could profitably be adulterated with mineral phosphates, to detect which Wagner devised the well-known citric acid test that, with certain modifications, has remained in force ever since.

Although basic slag is a by-product it is nevertheless standardised and the grades in commerce usually contain a percentage of phosphorus equal to that present in 10 to 20 parts of P_2O_5 or 22 to 44 parts of tricalcic phosphate. Such slag is sometimes said to *contain* 22 to 44 per cent. of tricalcic phosphate but this is incorrect: the actual nature of the phosphorus compound is not yet known but it is probably a complex silico-phosphate[1]: the method of expression

[1] Morison (*Journ. Agric. Science*, 1909, III. 161–170) shows that it is probably a compound of the type $(MO)_5M'O$, SiO_2, P_2O_5. He actually found $(CaO)_5FeO$, SiO_2, P_2O_5. There is no evidence for the

as tricalcic phosphate is convenient as it allows instant comparison with other phosphatic fertilisers. It contains a certain amount of free lime, usually about 2 per cent., which gives a distinct alkaline reaction, in addition a considerable quantity of the combined lime can probably act as a base in the soil (see p. 88).

The medium and higher grade slags are largely soluble in a 2 per cent. solution of citric acid; 80 per cent. solubility was long guaranteed so that the soluble phosphate came out at 20–34 per cent. Nowadays certain slags are often sold on the citric acid figure alone. The lower grades are often but not always less soluble. The solubility in citric acid depends very much on the mode of preparation of the slag, increasing with the addition of silica and decreasing with the addition of fluorspar: the acid slags are practically insoluble. There has been some discussion as to how far citric solubility is a satisfactory criterion of manurial value, and the whole subject is now under investigation at two or three centres.

Basic slag is not soluble in water but it dissolves in carbonic acid which occurs in the soil-water, and therefore readily comes into solution in the soil. The action is hastened by its fine state of division, at least 80 per cent. being guaranteed to pass a sieve with 100 meshes to the linear inch.

It has given remarkable results on clay grass lands, and has probably been the cause of greater improvement on these than any other single factor, its action being to bring on the white clover which

statement often made that basic slag is a tetra basic phosphate. A further paper on the subject is by Krol, *Journ. Iron and Steel Institute*, 1911, p. 126.

then so increases the nitrogenous organic matter of the soil that greater growth of grass becomes possible. As its effect is at a maximum when the herbage is most scanty it is best to begin with a heavy dressing, say 8 to 10 cwt. per acre in the first year, followed by 5 cwt. at a later date. Experiments at Cockle Park[1] and elsewhere have demonstrated the great increase in feeding value of the herbage treated with slag. It has also had a remarkable effect on the downland pastures of Sussex and Hampshire, seen for example at Sevington in Hampshire[2], and on Prof. Somerville's farm, Poverty Bottom, at Newhaven. The older practice was to apply it in autumn or winter but later work has shown that spring dressings are also good.

In dry situations, however, it proves less effective, *e.g.*, on some of the Hertfordshire gravels and on the downland of East Kent. Sometimes the failure is due to lack of potash, which can be remedied by addition of kainit[3].

It is valuable on arable land for swedes and turnips wherever there is any tendency to finger and toe, and it also increases the feeding value of the roots.

The usual price of slag is:

"Soluble phosphate"	Equivalent to P_2O_5	Price f.o.r.[4]	Price per unit Phosphate	Price per unit P_2O_5
20 per cent. ..	9·1	27*s.*	1*s.* 4*d.*	2*s.* 11*d.*
34 per cent. ..	15·5	47*s.*	1*s.* 4½*d.*	3*s.*

Over 3½ million tons are produced each year.

[1] These are summarised in Prof. Somerville's paper, *Journ. Bd. of Agric.*, Supplement, Jan. 1911.

[2] *Journ. Bath and West Society*, reported annually, 1901 onwards.

[3] *E.g.*, see Woburn Experiments, *Journ. Roy. Agric. Soc.*, 1907.

[4] See footnote, p. 200.

Comparison of basic slag and superphosphate. On heavy clays, on downland pasture and in wet situations slag is generally better than superphosphate. For roots, potatoes, hops and other short season crops superphosphate is usually better than slag. In Hendrick's swede experiments[1] at Aberdeen superphosphate gave on the whole the largest increases in crop, but where finger and toe was prevalent it required the addition of lime. In the Irish experiments basic slag and superphosphate gave approximately equal results[2]. Some of the Yorkshire experiments giving the same result are set out on p. 146. From these and other experiments we may conclude that the two fertilisers are nearly equally effective and that the choice between them must turn on special circumstances such as climate, the wetness, heaviness, etc., of the land. It is not uncommon or unwise to apply both to the soil—separately, not mixed.

Other phosphates

From time to time other attempts have been made to utilise natural phosphates by converting them into more readily soluble compounds, the most interesting of which are those of Wilborgh and of Palmaer, both of the Polytechnic Institute of Stockholm. Large quantities of impure natural phosphates are obtainable from the North of Sweden, which Wilborgh attempted to utilise by fusing with sodium carbonate. The product was good, but too costly. Palmaer adopted an electrolytic method, and acted on the phosphate

[1] Aberdeen College, *Bull.* Nos. 1, 4 and 8, 1904, 1906, 1907. Also *Trans. Highland and Agric., Soc.*, 1906.

[2] *Journ. Dept. Agric.*, Ireland, 1913.

with the acid solution collecting round the anode during the electrolysis of sodium chlorate, then precipitated with the alkaline solution from the kathode, and finally filtered to recover the sodium chlorate which was once more electrolysed. The material is found to be very satisfactory[1].

Sometimes mineral phosphates themselves are ground and sold as fertilisers but no great quantities are used in this country. Beneficial results have been obtained in many parts of the United States, especially on sour derelict lands: indeed so popular are the mineral phosphates that basic slag is not produced in spite of the vast iron and steel industry. Moorland soils also frequently respond to mineral phosphates. Neither of these results, however, affords much guidance as to what other soils will do; in particular, moorland soils respond more than others to fertilisers of low solubility. Increased crops, however, have been obtained at Cockle Park[2].

CHAPTER IX

POTASSIC FERTILISERS

THE system of agriculture long in vogue in this country consisted in selling grain and meat from the farm but returning the straw to the land in the form of manure. As the straw contains a large proportion of the potash while the grain and meat contain much

[1] Von Feilitzen, 8th Congress, *Applied Chemistry*, vol. xv. p. 85; also *Journ. für Landw.*, 1910, p. 33, and 1911, p. 371

[2] See *Guide* for 1913, pp. 39, 40.

phosphate it is evident that the tendency of the system was to keep the potash on the farm and to reduce to a minimum the need for buying potassic fertilisers.

But with the more varied types of cropping of recent times, and above all the extended growth of potash-needing crops like mangolds, potatoes, and, on

Fig. 27. Effect of potassic fertilisers on mangolds. (Barnfield, Rothamsted.)

Left hand plot—Superphosphate and nitrogenous manure, no potassium salts.

Right hand plot—Superphosphate, nitrogenous manure and potassium salts.

the Continent, sugar beet, there has arisen the necessity for applying potash to the soil and for this purpose large quantities of potassium salts are imported. These all come from Stassfurt in Prussia, and, so far as is known, no other deposits of economic importance exist elsewhere. A certain amount is present in wood

ashes, but there is not usually sufficient of this material available to affect the supply to the farm.

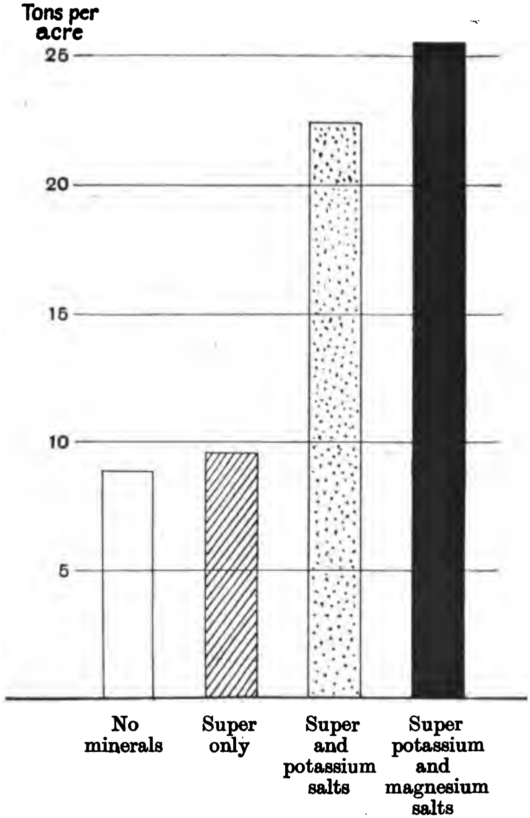


Fig. 28. Effect of mineral manures on the yield of mangolds already receiving nitrogenous manure (ammonium salts and rape cake). Barnfield, Rothamsted. (Roots, tons per acre, average 37 years, 1876–1912.)

It is only since the "sixties" that the Stassfurt salts have been on the market, but the demand has

grown so rapidly, especially since 1900, that nearly 10 million tons per annum of the crude salts representing approximately one million tons of K_2O were sold before the war, mainly for agriculture. Three salts are in common use here[1]: sulphate of potash, muriate of potash, and kainit. There is also a fourth known as 40 per cent. potash manure salts, but the sale of this was restricted to Germany.

Potash is particularly needed for certain special crops like mangolds (Figs. 27 and 28) and potatoes; indeed in this country it is usually associated with dairy and potato farming. A usual dressing is 2 cwt. of muriate or sulphate of potash for potatoes or 4 cwt. of kainit for mangolds. Also, it is often effective on grass land, especially on thin soils, and on leguminous crops. It may be needed for other crops as the standard of farming rises and the yields are forced up: the natural supplies of potash in the soil are not always sufficient for the higher crops that ought to be obtained. Thus on the Rothamsted barley plots phosphates give a considerable increase in yield, but a still further increase is obtained by supplying potassium salts in addition (Table VI).

TABLE VI. *Effect of manures on the yield of barley. Rothamsted: average* 60 *years*, 1852–1911

Treatment of barley	Dressed grain bushels per acre	Straw cwts. per acre
Sulphate of ammonia only	25·5	14·7
,, ,, ,, + potash	28·0	16·9
,, ,, ,, + super	38·2	22·0
+ super + potash	41·5	25·0

[1] For a full description of the Stassfurt deposits see *The Potash Salts, their Production and Application.* Dr Groth. Lombard Press, London.

Another instance is afforded at Saxmundham (Table VII). The soil is heavy and potash was not expected to give a return, nor did it so long as the yields were low. But directly phosphates are added the yield goes up and the potash-needing plants—beans, peas and lucerne—can now increase beyond the capacity of the soil supplies of potash. Fresh additions of potash are therefore necessary for these crops, but not, however, for barley or wheat.

TABLE VII. *Effect of potassic manures on crops. Saxmundham: average yields* 4 *years*, 1910–1913

	Lucerne[1]	Beans and Peas		Roots	Barley		Wheat	
		Corn	Straw		Grain	Straw	Grain	Straw
	cwt.	bus.	cwt.	tons	bus.	cwt.	bus.	cwt.
No manure	25	20·8	14·3	6·7	21·3	17·5	19·4	20·5
2 cwt. nitrate of soda	25	22·9	16·8	5·3	26·5	26·0	23·2	30·3
2 cwt. each nitrate of soda and superphosphate	58	31·7	26·3	15·2	34·1	28·0	29·2	32·8
2 cwt. each nitrate of soda superphosphate + 1 cwt. muriate of potash	62	35·0	28·1	16·4	34·2	29·7	25·3	34·0

[1] 6 years, 1903–1908.

Whenever land of any kind has been improved and made to yield higher crops a trial should always be made to see if potash is needed.

Light sandy soils respond considerably to dressings of potash, so also do moorland soils. It is because of the wide occurrence of these two types of soil in North Germany and of moorland soils in Sweden that potash is so much used in those countries; the demand is still further increased by the great quantity

of sugar beet grown. Light chalky soils also respond to potash. Although all three salts are easily soluble they are readily precipitated in the soil and only wash out with difficulty so that the drainage-water is practically free from potash.

The main effects of potash on the plant are three. It facilitates either the production or the translocation of sugars and starches from the leaf and hence its value for sugar- and starch-making crops like sugar beet, mangolds and potatoes.

It stiffens the straw of cereal crops and of the grass tribe generally: at Rothamsted the wheat and grass crops growing on the plots deficient in potash tend to become laid, especially in bad seasons.

Further, it enables the plant to withstand adverse conditions of soil, climate or disease, etc. The plants well supplied with potash at Rothamsted do better in bad years—whether of wetness or of drought—than the others: they are also more resistant to rust and other diseases. On the potash-starved plots the grass not only gets laid, but is also liable to attacks of the fungus *Epichloe*, and in addition the seed heads are often barren; the mangolds get badly attacked by the fungus *Uromyces betae*; the wheat is always subject to rust and the tips of the leaf begin to die early in the season and then the edges turn yellow for some distance down. Elsewhere also dressings of potash have enabled plants to withstand pests: flax in Ireland, tomatoes in glasshouse culture, spring oats affected by eelworm have all furnished cases in point. Potash manures also tend to counteract rankness of growth and therefore find valuable application for glasshouse and nursery work.

In farm practice the potash should be applied either to potatoes or to mangolds: the cereals in the rotation can then very well take up the unused material. On the whole kainit is better for mangolds while the sulphate or muriate is better for potatoes; between sulphate and muriate, however, there is little to choose[1]. Where potash is wanted for grass land kainit is perhaps the better and on the whole cheaper: the results of the Yorkshire experiments[2] which are typical of many others are given in Table VIII.

TABLE VIII. *Yorkshire experiments on meadow hay. Cwts. per acre*

		Garforth	Horton
No manure		32	36
Nitrate of soda		43	43
Nitrate of soda +	super	44	45
	steamed bone flour	43	45
	slag	44	45
Nitrate of soda + phosphates + potash as	sulphate	43	49
	muriate	45	51
	kainit	42	52

At Garforth the potash has given no return; at Horton, however, distinct increases have been obtained.

In glasshouse practice sulphate of potash is generally considered better than kainit.

The muriate and sulphate are single potassium salts but kainit is not: it is a mixture containing sodium and magnesium salts as well which have distinct fertilising value although they are not as effective as potash. Dressings of potash and particularly of kainit have occasionally reduced the crops, apparently because interaction with the calcium carbonate in

[1] See *10th Annual Report, Durham Coll.*, 1902, p. 30, for details of an experiment on this subject.

[2] *Guide to the Garforth Experiments*, 1913, p. 3.

the soil gives rise to potassium carbonate which has a bad effect on the soil texture[1].

The composition and prices of the three manures are as follows:

	Containing potassium equivalent to	Price per ton f.o.r.	Price per unit of K_2O
Sulphate of potash ..	48·5 % of K_2O	£11	4*s.* 6½*d.*
Muriate of potash ..	45 ,,	£10. 7*s.* 0*d.*	4*s.* 7*d.*
Kainit	12·0 ,,	£2. 12*s.* 0*d.*	4*s.* 4*d.*

Wood ashes contain about 10 per cent. of K_2O and are thus nearly as rich as kainit; but the potash occurs as the highly soluble carbonate and is rapidly washed out by rain. To be of any use, therefore, the ashes must be collected at once. Phonolite and felspar also contain potash but they proved ineffective in the Woburn experiments.

CHAPTER X

MANURES SUPPLYING ORGANIC MATTER: FARMYARD MANURE

ORGANIC matter is a general expression used to denote substances of animal or vegetable origin in contradistinction to the nitrates, phosphates and potassium salts which are termed inorganic. It contains carbon, hydrogen and oxygen and is combustible: this property is used in practice for distinguishing it from the inorganic matter of soils or fertilisers which is usually non-combustible.

Organic matter differs in two important directions

[1] An instance is afforded at Garforth: see *Guide*, 1913, p. 20.

from the mineral substances studied in the preceding chapters. Nitrates, phosphates, and potassium salts are directly assimilated by plants; organic matter apparently is not, and it derives no fertilising value from its three characteristic components but only from any nitrogen, phosphorus or potassium it may contain. Before these elements can be utilised by the plant, decomposition must take place in the soil and this is effected by moulds and bacteria, and gives rise to ammonia, carbon dioxide and certain complex residues grouped together as humus. The fertilising value of the organic matter depends very much on the rate at which this decomposition proceeds, which in turn is determined by the bacterial efficiency of the soil and by the nature of the substance. Protein and the simpler compounds such as urea are rapidly decomposed to form ammonia in the soil, but the more complex substances which occur in straw, wool, etc., break down more slowly. Field experiments have shown that the effect of ammonia only lasts for one season, any excess not taken by the plant being washed out during winter. The easily decomposed substances therefore only act for one year: they are called quick acting manures. The more complex substances decompose more slowly and last more than one year: they are called slow acting or lasting manures. There is no special virtue in a slow acting manure: one pound of nitrogen will only yield the same amount of ammonia whether the decomposition process takes weeks or years: indeed there is the disadvantage that a slow acting manure represents capital locked up while the quick acting manure gives a quick return. It will be seen below

that all the protein substances—dried blood, rape cake, guano, the cake fed to animals—are quick acting and may last only one year, while straw and wool (*i.e.*, shoddy) are slower and last longer in the soil.

The second great distinction between organic matter and artificial fertilisers lies in their effect on the soil. Artificial fertilisers have comparatively little action as a rule; organic matter, on the other hand, causes great improvement in physical condition and in water-holding capacity. Some of the Rothamsted plots receiving no organic fertiliser have now so bad a texture that difficulty is experienced in getting a tilth, and crops like roots that are dependent on a fine tilth suffer accordingly: cereals, however, are not affected. Extreme cases arise where artificial fertilisers are of practically no value while the organic manures lead to considerable increases in crop: such cases are not common in this country and are usually confined to dry sands, but they not infrequently arise in subtropical conditions and are seen for example in Madras, Java, etc., where neither nitrates, phosphates nor potash give appreciable crop increases while the oil cake residues have considerable fertilising value[1]. In this country, however, organic matter cannot be regarded as necessary for crops however desirable it may be from the point of view of getting a tilth. Large crops of wheat, barley, mangolds and grass are regularly grown at Rothamsted on land which for 70 years has received no organic manure and the crops show no signs of falling off. A strict comparison was made by Hansen on a light loam

[1] See, for instance, Dr Barber's *Report of the Samalkota Experiment Station*, 1912.

and on a sand at Askor (S. Jutland) where farmyard manure was compared with a dressing containing equal amounts of nitrogen, potash and phosphates in the form of artificials (nitrate of soda, superphosphate, and kainit) and almost always gave poorer results[1].

But if organic matter is not needed by the crop it is commonly required by the soil: and experiments all over the country have shown that the best *economic* results are obtained by a judicious combination of artificial fertilisers with organic manures.

Farmyard manure. Farmyard manure consists of the solid and liquid excretions from the animals together with the litter. It is the oldest and the commonest of all the fertilisers: indeed in the "sixties" and "seventies" beasts were kept on the farm solely for the value of the manure they made, and the practice still persists to some extent.

About half of the bulky food supplied to the animal (hay, straw, etc.) and nearly all the concentrated food (corn, cake, etc.) can be broken down by the digestive fluids in its body; the remainder cannot, and simply passes out as solid excreta or faeces. The digested portion enters the circulation and is used by the animals, most of the nitrogen and potash then finds its way into the urine. The compounds in the urine thus represent the easily decomposed part of the food, and in the soil they readily change to ammonia and other useful substances. On the other hand the solid excreta, which could not be broken down in the body, prove somewhat resistent in the soil. Hence the urine is the most valuable part of the manure.

[1] Fr. Hansen and J. Hansen, *Tidsskrift for Landbrugets Planteavl*, 1913, xx. 345.

The richest manure is therefore that which contains the most and the richest urine. Now the richness of the urine clearly depends on the food, for, as we have just seen, the urine gathers up most of the digested nitrogen; *hence the more digestible nitrogen the food contains, the richer will be the manure produced.* Concentrated foods like cake, which are rich in digestible nitrogen, therefore improve the dung. But it does not follow that the richest cake gives the richest manure: richness of cake depends on the oil present, while richness of the manure depends on the nitrogen. A linseed cake containing 7 per cent. of oil gives richer manure than a more costly cake containing 10 per cent., and decorticated cotton cake gives a richer manure still.

But the richness of the urine also depends on the animal. Fatting animals keep back very little of their nitrogen—only about 5 per cent.—and pass most of it out in the urine. Growing animals and milch cows keep back considerably more, so that the urine is correspondingly poorer. Consequently *fatting animals make better manure than young stock or dairy cows.*

It is clear also that the urine must on no account be allowed to waste: sufficient suitable litter must be added to absorb it all. Straw, peat moss, and bracken are used for the purpose, and these substances not only absorb the urine but also enrich the dung because they themselves contain valuable fertilising materials.

Straw is much the commonest form of litter: it has considerable power of absorbing urine especially when well trodden by the beasts and it also contains a fair amount of nitrogen and of potash. Its composition varies somewhat (Table IX), but on an average one ton contains nearly 12*s*. worth of fertilising material.

Bracken compares very favourably with straw and should be used whenever opportunity offers, especially on heavy soils: on sandy soils, however, it suffers from the drawback—which, however, is not always very important—that it decomposes more slowly.

Peat moss is not generally used on farms as sufficient straw is usually available, but in city stables it is often preferred by reason of its higher absorbent power. Peat moss manure may be expected to contain more ammonia than ordinary manure, but on the other hand the peat moss does not itself contribute as much to the manure as straw, being poorer in potash and phosphoric acid. Further it does not so readily decompose and is therefore less useful on light soils.

TABLE IX. *Typical analyses of the materials used for litter.* 100 *lbs. of each material contain:*

	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
Oat straw	0·50	0·24	1·00
Wheat straw ..	0·45	0·24	0·80
Barley straw ..	0·40	0·18	1·00
Bracken	1·4	0·2	0·1
Peat moss	0·8	0·1	0·2

The manure as made. Knowing the weight and composition of the food and litter and deducting the food constituents retained by the animal, it is easy to calculate the amount of fertilising materials in any particular lot of farmyard manure. Experiments by Voelcker, Wood and the writer show that the calculation does not come out right, the quantity of nitrogen found in the manure being usually about 15 per cent. less than was anticipated. The loss does not take place in the animal: physiological experiments

have shown that the whole of the nitrogen of the food is excreted in the urine or faeces and that there is no production of gaseous nitrogen: the loss goes on through bacterial action while the manure is in the stall and before it is removed. After making this allowance we can find the total quantity of fertilising material in the heap. The amount per ton, however, depends on the amount of water present and this varies with the different animals; sheep and horses giving more concentrated urine and faeces than cattle and pigs.

In view of the great variability in the quantity and composition of the litter and of the food it is obvious that no very definite figures can be given for the composition of farmyard manure. Numerous analyses have been made; a few are given in Table X.

Changes on storing. Dung cannot generally be used directly it is made but often has to be kept for a period and applied to the land when convenient. Bacteria, moulds, etc. cause considerable decomposition during storage and much heat is evolved. Relatively dry manure, *e.g.*, horse dung, rises considerably in temperature; wetter manure like cow dung does not because of the great amount of heat needed to warm up all the water present and because much water means little air. This production of heat involves the combustion of material in the heap so that there is a corresponding loss of dry matter. The loss of nitrogen may be considerable and is of course additional to the loss of 15 per cent. incurred during the making.

The changes that take place are very complex and are not yet clearly known: they are under investigation at Rothamsted. Exposure to air and rain greatly increases the losses, shelter on the other hand

TABLE X. *Composition of farmyard manure (Rothamsted)*

	100 lbs. contain						1 ton contains					
	Dry matter	Nitrogen Total	Nitrogen as ammonia	Nitrogen as amide	P_2O_5	K_2O	Dry matter	Nitrogen Total	Nitrogen as ammonia	Nitrogen as amide	P_2O_5	K_2O
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Cake fed 1908	31·6	0·69	0·06	0·14	0·27	0·53	708	15	1·3	3·1	6·1	12
1909	27·5	0·72	0·18	0·25	0·19	0·48	616	16	4·1	5·5	4·3	11
1910	22·3	0·60	0·15	0·13	0·20	0·33	500	13	3·4	2·8	4·5	7·4
Average 1904–13	27·4	0·77	0·18	0·16	0·39	0·60	613	17	4	3	9	13
No cake used 1908	24·2	0·50	0·02	0·08	0·12	0·37	542	11	0·6	1·7	2·7	8
1909	28·3	0·64	0·03	0·10	0·13	0·31	634	14	0·7	2·2	2·8	7
1910	19·8	0·46	0·01	0·06	0·08	0·20	444	10	0·3	1·4	1·8	4·5
Average 1904–13	27·2	0·54	0·04	0·09	0·23	0·67	610	12	1	2	5	15

decreases them. Thus the losses are least in a compact heap stored under cover, or, what comes to the same thing, in manure made in a box and kept under the animal. They become greatest—amounting to 40 per cent. or more—when the manure is made in open yards and then loosely packed into heaps and exposed to rain in the open. In the Rothamsted experiments the losses on storage for three months were:

Compact heap under cover: 4 per cent. of nitrogen.
Loose heap under cover: 7 per cent. of nitrogen.
Heap exposed to open: 33 per cent. of nitrogen.

The loss fell mainly on the ammonia and amides, *i.e.*, on the easily available nitrogen. (Fig. 29.)

On this basis a 100 ton heap of manure valued at 5*s*. a ton would have lost over £8 worth of material in three months' exposure to the weather. The best way of reducing loss in practice is to make the manure in boxes or covered yards and to store it in heaps sheltered as much as possible, compacted by means of a loaded cart and arranged so as to reduce the area exposed to rain.

Formerly it was supposed that the loss of nitrogen took place mainly as ammonia, and farmers were advised to mix superphosphate, gypsum, or soil with the heap as "fixers," but recent work is against this view and direct experiment has shown the futility of these precautions. Shelter and compacting seem the best methods of reducing the loss.

The liquid draining away from the heap and from the yards is of great fertilising value and should not be wasted[1]. It may be applied direct as liquid manure,

[1] Experiments with liquid manure are recorded by Hendrick, North of Scotland College of Agric., *Bull.* No. 19, 1915.

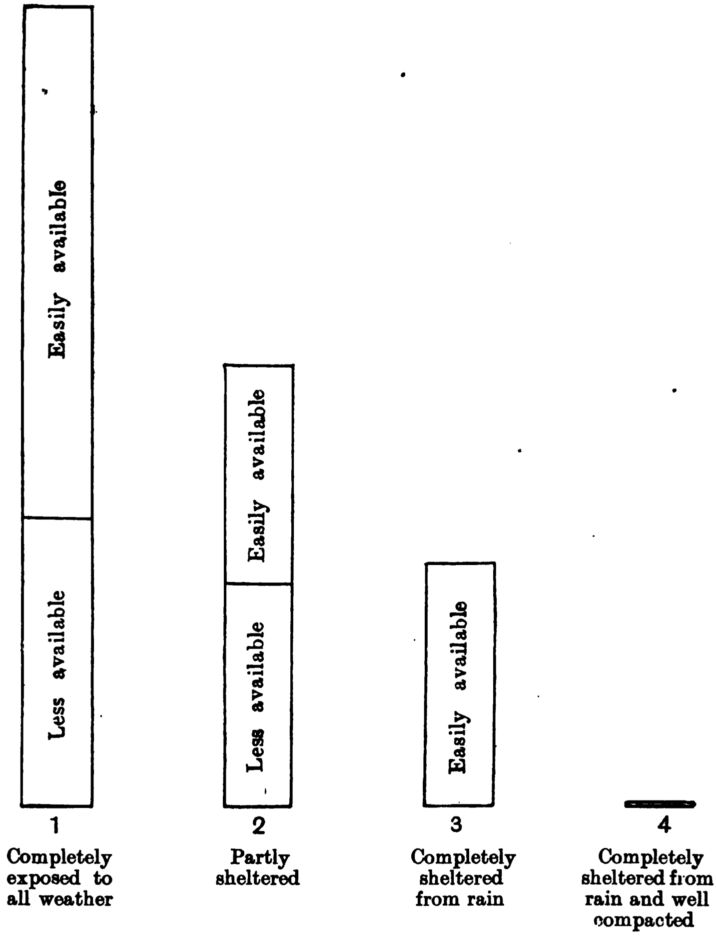


Fig. 29. Relative amounts of nitrogen lost from manure heaps variously exposed to weather.

or pumped back on to the heap just before carting on to the land.

Effect of the manure. Practical men distinguish between "long" manure which has suffered only little decomposition, and retains its straw in the original long state, and "short" manure, where decomposition has proceeded so far that much of the straw has disintegrated to form a black buttery mass. The "short" manure is often richer in composition than the "long" manure, but it is more costly to produce because as much as two tons of fresh manure may be needed to make a ton of short manure, while the same quantity of material would yield 35 cwt. or more of long manure. For this reason long manure is most in favour on the farm, where costs have to be considered, while short manure is preferred in the garden.

Long manure is of special advantage on a heavy soil since the straw helps to keep the soil open and to facilitate drainage and the action of winter frost. On light land or in dry districts this is a disadvantage because the undecomposed straw may open up the soil too much and cause loss of water. In such cases the long manure is best applied in autumn so that these actions can proceed unhindered and disintegration and decomposition can begin before growth becomes vigorous in spring. It can, however, be applied in spring when it is buried in the furrows as in potato growing.

Short manure can be used at almost any time of the year and is therefore necessary for many garden purposes.

The distinction between cake-fed dung and ordinary dung produced by store cattle has already been

discussed. Cake-fed dung, as shown on p. 151, is richer in nitrogen than dung produced on hay and roots only, and is even better than the figures indicate because the extra nitrogen is largely in the form of ammonia and amides produced from the liquid excreta. These compounds readily change to nitrates in the soil and so give rise to increased crops. Some of the data obtained at Rothamsted are given in Table XI.

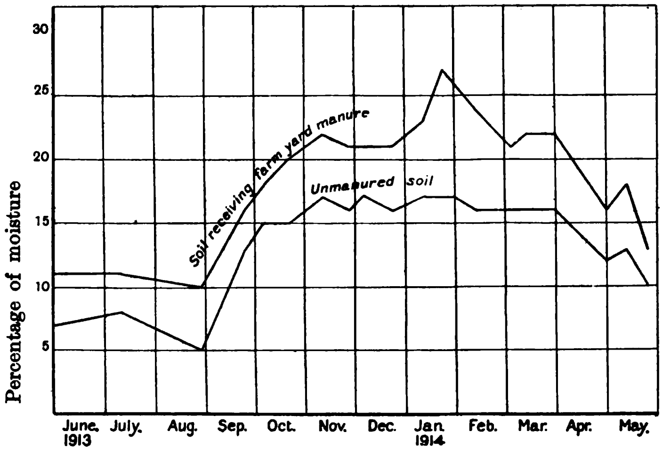


Fig. 30. Curves showing effect of farmyard manure on water content of soils. (Broadbalk field, Rothamsted.)

On the heavy soil at Rothamsted and the similar soil at Garforth the advantage of the cake feeding was not seen after the second year; experiments on other types of soil would be needed to discover how far this effect is general.

The two most striking physical effects of farmyard manure on the soil are the improvement in tilth already referred to, and the improvement in the water-holding capacity. Fig. 30 gives curves showing the

TABLE 11. *Comparison of effects of cake-fed and ordinary dung. Little Hoosfield. Total produce per acre unmanured* = 100

		Swedes 1904	Barley 1905	Man-golds 1906	Spring Wheat 1907	Swedes 1908	Barley 1909	Wheat 1910	Man-golds 1911	Wheat 1912	Mean
Unmanured		100	100	100	100	100	100	100	100	100	100
Ordinary dung, 1st crop		139	150	114	189	136	146	106	136	177	144
Grown on residues only, no further dressing of dung	2nd crop	—	199	109	150	124	135	118	108	138	135
	3rd crop	—	—	114	148	110	121	113	122	151	126
	4th crop	—	—	—	128	104	107	104	120	139	117
Unmanured		100	100	100	100	100	100	100	100	100	100
Cake-fed dung, 1st crop		155	212	167	234	157	172	155	143	163	173
Grown on residues only, no further dressing of dung	2nd crop	—	160	121	161	133	139	129	120	144	138
	3rd crop	—	—	127	137	118	111	106	118	122	120
	4th crop	—	—	—	107	99	114	105	118	135	113

percentage of water in the dunged plot and in the adjacent unmanured plot of the Broadbalk wheat field during 1914: it will be seen that the former is invariably the moister even in the very dry June. Indeed so great is the water-holding capacity of the soil that the rain-water does not distribute itself uniformly in the soil but remains in the top few inches and rarely gets down to the drains in sufficient quantity to cause them to run. The unmanured soil, on the other hand, is easily permeable to water, becomes wet throughout its depth soon after rain has fallen, and readily transmits water to the drains.

Farmyard manure considerably influences the microscopic population of the soil, causing the numbers of bacteria and other organisms to increase and bringing into prominence certain changes that are not conspicuous in ordinary soils.

On the heavily dunged Broadbalk plot (14 tons annually) about 30 to 50 per cent. of the nitrogen in the dung is absorbed by the crop or washed out, and about 20 per cent. accumulates in the soil, but the remainder cannot be accounted for, and the simplest explanation is that it is lost as gaseous nitrogen. Equally serious losses seem to occur wherever dung is used in heavy dressings, *e.g.*, in market gardening, in certain glasshouse work, and in intense mangold growing. On the other hand there seems to be less loss where the dung is only applied once in four years as in ordinary farming, and where proper rotations and well-balanced manurial schemes are adopted. The cause of the loss is being investigated at Rothamsted.

The use of farmyard manure. As a fertiliser farmyard manure is well supplied with nitrogen and potash,

but deficient in phosphates, and the best results are obtained when the necessary artificial manures are applied somewhere in the rotation. The dung is usually put on to the roots, especially to the mangolds and potatoes, some also can go on the young seeds and some to the meadow land. The time of application depends on the climate, the crop, and the labour available. So far as labour is concerned it is an advantage to apply the manure in autumn or winter and get it worked in ready for the spring, and this can be done in districts with an annual rainfall of 30 inches or less. In wetter districts, however, with a rainfall of 35 inches or more, better results have been obtained by spring dressings. Cases have arisen where autumn dressings on seeds mixtures have kept the land so wet that young clover plants have suffered. Berry has shown in the west of Scotland that spring dressings gave increases of 50 to 60 per cent. in the potato and turnip crops while autumn dressings only gave 25 per cent. increase over the control plots[1].

Farmyard manure sometimes contains many weed seeds and the old practice was to kill them by throwing the heap up loosely and allowing it to become hot. But the modern threshing machine is considerably more efficient than the older form, and the weed seeds are more completely removed with the cavings; so long as these are not thrown on to the manure heap there is little if any need to take special precautions against weeds. On a clean farm even the cavings can be used with advantage. Purchased town manure should, as far as possible, be clamped in autumn and left as long as convenient to kill weeds.

[1] *West of Scotland Agricultural Bulletin*, No. 65, 1914.

Foods	Valuation per ton a									
	Nitrogen					*Phosphoric Acid*				
	Per cent. in food	Value at 15*s.* per unit		Half of value to manure		Per cent. in food	Value at 3*s.* per unit		Three-quarters of value to manur	
		s.	*d.*	*s.*	*d.*		*s.*	*d.*	*s.*	*d.*
1. Decorticated cotton cake.. ..	6·90	103	6	51	9	3·10	9	4	7	0
2. Undecortd. cotton cake (Egyptian)	3·54	53	2	26	7	2·00	6	0	4	6
3. Undecortd. cotton cake (Bombay)	3·10	46	6	23	3	2·50	7	6	5	7
4 Linseed cake	4·75	71	4	35	8	2·00	6	0	4	6
5. Linseed	3·60	54	0	27	0	1·54	4	7	3	5
6. Soya-bean cake	6·85	102	8	51	4	1·30	3	11	2	11
7. Palm-nut cake	2·50	37	6	18	9	1·20	3	7	2	8
8. Cocoa-nut cake	3·40	51	0	25	6	1·40	4	2	3	1
9. Earth-nut cake	7·62	114	4	57	2	2·00	6	0	4	6
10. Rape cake	4·90	73	6	36	9	2·50	7	6	5	8
11. Beans	4·00	60	0	30	0	1·10	3	4	2	6
12. Peas	3·60	54	0	27	0	0·85	2	7	1	11
13. Wheat	1·80	26	10	13	5	0·85	2	7	2	0
14. Barley	1·65	24	10	12	5	0·75	2	3	1	8
15. Oats	2·00	30	0	15	0	0·60	1	10	1	5
16. Maize	1·70	25	6	12	9	0·60	1	9	1	4
17. Rice meal	1·90	28	8	14	4	0·60	1	9	1	4
18. Locust beans	1·20	18	0	9	0	0·80	2	5	1	10
19. Malt	1·82	27	4	13	8	0·80	2	5	1	10
20. Malt culms	3·90	58	6	29	3	2·00	6	0	4	6
21. Bran	2·50	37	6	18	9	3·60	10	10	8	2
22. Brewer's grains (dried)	3·30	49	4	24	8	1·61	4	10	3	8
23. Brewer's grains (wet)	0·81	12	4	6	2	0·42	1	3	0	11
24. Clover hay	2·40	36	0	18	0	0·57	1	9	1	4
25. Meadow hay	1·50	22	6	11	3	0·40	1	2	0	11
26. Wheat straw	0·45	6	8	3	4	0·24	0	9	0	7
27. Barley straw	0·40	6	0	3	0	0·18	0	6	0	4
28. Oat straw	0·50	7	6	3	9	0·24	0	9	0	7
29. Mangolds	0·22	3	4	1	8	0·07	0	3	0	2
30. Swedes	0·25	3	10	1	11	0·06	0	2	0	1
31. Turnips	0·18	2	8	1	4	0·05	0	2	0	1

anure					Compensation value for each ton of the food consumed								
Potash					Food made into dung				Food consumed on land				
Per cent. food	Value at 4*s.* per unit		Three-quarters of value to manure		(1) Before one crop has been grown or removed		(2) After one crop has been grown or removed		(3) Before one crop has been grown or removed		(4) After one crop has been grown or removed		No.
	s.	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*	
2·00	8	0	6	0	64	9	32	4	85	6	32	4	1
2·00	8	0	6	0	37	1	18	6	47	9	18	6	2
1·61	6	5	4	10	33	8	16	10	43	0	16	10	3
1·40	5	7	4	2	44	4	22	2	58	10	22	2	4
1·37	5	6	4	2	34	7	17	3	45	4	17	3	5
2·20	8	10	6	7	60	10	30	5	81	6	30	5	6
0·50	2	0	1	6	22	11	11	5	30	6	11	5	7
2·00	8	0	6	0	34	7	17	3	44	9	17	3	8
1·50	6	0	4	6	66	2	33	1	89	1	33	1	9
1·50	6	0	4	6	46	11	23	5	61	8	23	5	10
1·30	5	2	3	10	36	4	18	2	48	4	18	2	11
0·96	3	10	2	10	31	9	15	10	42	6	15	10	12
0·53	2	1	1	7	17	0	8	6	22	5	8	6	13
0·55	2	2	1	7	15	8	7	10	20	8	7	10	14
0·50	2	0	1	6	17	11	9	0	23	11	9	0	15
0·37	1	6	1	1	15	2	7	7	20	4	7	7	16
0·37	1	6	1	1	16	9	8	4	22	6	8	4	17
0·80	3	2	2	4	13	2	6	7	16	9	6	7	18
0·60	2	5	1	10	17	4	8	8	22	9	8	8	19
2·00	8	0	6	0	39	9	19	10	51	6	19	10	20
1·45	5	9	4	4	31	3	15	7	38	10	15	7	21
0·20	0	10	0	8	29	0	14	6	38	11	14	6	22
0·05	0	2	0	1	7	2	3	7	9	9	3	7	23
1·50	6	0	4	6	23	10	11	11	31	0	11	11	24
1·60	6	5	4	8	16	10	8	5	21	4	8	5	25
0·80	3	2	2	4	6	3	3	1	7	7	3	1	26
1·00	4	0	3	0	6	4	3	2	7	6	3	2	27
1·00	4	0	3	0	7	4	3	8	8	11	3	8	28
0·40	1	7	1	2	3	0	1	6	3	8	1	6	29
0·22	0	11	0	8	2	8	1	4	3	7	1	4	30
0·30	1	2	0	11	2	4	1	2	2	10	1	2	31

Finger and toe may be carried in manure if animals are fed on diseased roots.

Unexhausted values. Farmyard manure is in rather a different category from the artificial nitrogenous fertilisers in that its effects are not confined to the season of application but persist over several years. So long as a farmer continues in possession of the land he may hope to gain the benefit, but if he gives it up before the effects have come to an end he is entitled to compensation for the unexhausted value of the manure. The first tables for the guidance of valuers were drawn up by Lawes and Gilbert in 1870; they have been periodically revised and were reissued in 1914[1] by Voelcker and Hall, who recommend: (*a*) compensation should be payable in respect of half the nitrogen and three-quarters of the potash and phosphoric acid contained in the food, it being supposed that the remainder is lost: this amount to be paid in full where the manure has been applied to the land but no crop grown; (*b*) only one half the above amount is to be paid after the growth of one crop, and nothing is to be paid after the growth of two or more crops; (*c*) where, however, the food is fed on the land and not made into manure a higher scale of compensation should be payable, and credit be given for 70 per cent. of the nitrogen instead of the 50 per cent. in (*a*). This higher rate, however, is only applicable before a crop is grown because the extra benefit is attributed to the ammonia formed from the urine. Their values are given in Table XII.

[1] *Journ. Roy. Agric. Soc.*, 1914, LXXIV. 104.

CHAPTER XI

OTHER ORGANIC MANURES

(A) Animal Origin

Guano

Guano consists of the droppings of pelicans and other sea birds mixed with feathers, corpses of dead birds, remains of food, etc. It first came into this country from Peru in 1840 and rapidly achieved a high reputation. Other supplies have since been drawn from the numerous islands of the South Pacific. Deposits also occur on some of the islands off the coast of South Africa, especially Ichaboe, but these are retained for local consumption by the Union Government and are not generally shipped to Europe.

The composition and character of the guano depend on the conditions under which it has accumulated: in rainless areas it rapidly dries and remains undecomposed: in wet areas it suffers considerable decomposition and loses much of its nitrogen and organic matter, becoming more phosphatic. Thus two grades of guano are available: the nitrogenous, obtained in rainless districts, and the phosphatic, from moister regions.

The chief European supply of nitrogenous guano is from the rainless islands off the coast of Chili and Peru (lat. 7° to 20° S.). These are uninhabited and practically unvisited except at long intervals for the purpose of clearing the accumulations. The birds are

carefully preserved and care is taken by the Government and the large firms controlling the industry to ensure continuity of supplies for the future. The Ichaboe guano used in South Africa is collected annually after the breeding season is over: it is thus the freshest on the market. It usually contains less phosphate and more sand than the Peruvian guano of corresponding grade.

The phosphatic guanos are obtainable from a wider area and show larger proportions of phosphates and rock material by reason of the removal of the organic matter.

The composition of these guanos is as follows:

	Nitrogen	P_2O_5	Equivalent to tricalcic phosphate	Potash K_2O	Moisture and organic matter	Sand
Nitrogenous						
High grade Peruvian	10–14	9–11	20–24	2–4	60–70	7–12
Ordinary ,,	5–8	14–18	30–40	2–4	40–50	9–25
Ichaboe	8	9–14	20–30	2	50–60	15–25
Phosphatic	2·5–3·5	18–32	40–70	2–6	22–25	4–6

The high grade Peruvian guanos are used in horticulture, the ordinary grades in market gardens and occasionally for potatoes. It is quick acting and its effect at Rothamsted only lasts for one season (Table XIII). The phosphatic guanos are used both in market gardens and on farms. Other grades are treated with sulphuric acid to decompose the phosphates and form "dissolved guano," which is used in intense cultivation here and on sugar plantations in the West Indies.

TABLE XIII. *Effect of Peruvian guano on yield of crops. Rothamsted, Little Hoosfield. Total produce per acre* (*unmanured* = 100)

	Swedes 1904	Barley 1905	Man-golds 1906	Spring Wheat 1907	Swedes 1908
Unmanured	100	100	100	100	100
Year of application	135	182	142	160	120
1st year after application	—	90	109	105	90
2nd ,, ,,	—	—	112	90	91
3rd ,, ,,	—	—	—	88	88

	Barley 1909	Wheat 1910	Man-golds 1911	Wheat 1912	Mean
Unmanured	100	100	100	100	100
Year of application	152	124	120	107	138
1st year after application	80	77	94	98	93
2nd ,, ,,	89	64	97	84	90
3rd ,, ,,	90	87	89	90	89

Manufactured manures.—Fish guano. Fish guano or fish meal is obtained from fish which for any reason cannot be sold as food. The oil is first extracted by heat and pressure and the residue is then finely ground. It usually contains about 8 to 10 per cent. of nitrogen and 4½ to 9 per cent. of P_2O_5, equivalent to 10 to 20 per cent. of tricalcic phosphate; sometimes, however, more bone is present. It is a very useful manure for hops and in gardens, and has given good results when applied at the rate of 4 lbs. per rod to lawns on thin dry soils: it is also useful in farm practice. Care should be taken that it is

ground sufficiently to reduce the bone to a fine state. It must be got into the land quickly or it may be taken by birds.

Meat guano or meat meal, greaves

This is prepared from waste meat, condemned meat, refuse from slaughter houses, etc. It is first heated by steam to extract some of the fat and then subjected to pressure to remove as much more as possible—this process being adopted because of the high commercial value of fat for the soap and candle industries. The resulting cake is then broken up, dried, separated by shaking from foreign matter such as iron, glass, and is finely ground. Some of the fibrous material which still remains can only be disintegrated after treatment with sulphuric acid.

Some bone is always present, and definite quantities are added in certain cases to bring the composition to a uniform grade. The composition of various grades is as follows:

	Nitrogen	P_2O_5	Equivalent to Tricalcic phosphate
Pure flesh, dry and fat free	16·7		
High grade meat guano	8–9	4·6–7	10–15
Phosphatic meat guano (bone added) ..	4–5	16–18	35–40
Pure bone	5	22	48

Greaves is the waste material sent out by soap boilers and others; it is of substantially the same nature as meat guano, but not being a definitely manufactured manure it is liable to variations in composition and physical condition: it should only

be bought after analysis and comparison with samples of meat or fish guano.

Dried blood. This usually contains about 12 per cent. of nitrogen and it decomposes so rapidly that it commands a specially high price, and indeed is usually too costly—about £12 per ton—for ordinary purposes. It is, however, used in high class horticultural work, *e.g.*, for roses, carnations, vines, etc., and much of it is bought for America and for the better grade of mixed and patent fertilisers.

Hoofs and horns. Good samples of these contain 12 to 14 per cent. of nitrogen. When finely divided they are very effective for glasshouse work, and competition for the supply has sent up prices considerably. Another grade admixed with bone is also obtainable containing about 10 per cent. of nitrogen and 20–25 per cent. of phosphate. Coarser samples are of little use, and the rough material called scutch, sometimes offered for farm use and consisting of hair, hoof and bone, should only be applied after it has been well broken up.

(B) Vegetable Origin

Oil cakes

The large demand for oils and fats has created an enormous industry in pressing out oil from oil seeds. In some cases—*e.g.*, linseed and cotton—the residues have considerable value as cattle food: in other cases they are unsuitable for this purpose and are then offered as manure. The best known in this country is rape cake, which usually contains about 5 per cent. of nitrogen, 2 per cent. of P_2O_5 (*i.e.*, 4 per cent. of "phosphate") and 1 per cent. of potash.

Rape cake has long been used as a manure with good results[1] in this country and in India, and numerous experiments at Rothamsted have proved its value both on cereals and on roots (Table XIV). There is nothing to show, however, that it is worth a higher unit price than the various guanos, and yet higher prices are not uncommonly asked (Table XVII).

TABLE XIV. *Effect of rape cake on yields of barley and mangolds, Rothamsted*

	Plot	*Barley* Average yield for 60 yrs. (1852–1911)		Plot	*Mangolds* Average yield for 34 yrs. (1876–1912)
		Grain, bushels	Straw, cwts.		tons per acre
Unmanured ..	1·0	12·7	8·4	8·0	3·7
Complete artificial manures ..	4–AA	42·7	27·3	4–A	14·8
Farmyard manure (14 tons) ..	7–2	47·1	29·6	1–0[3]	18·9
Rape cake (9 cwt.)	1c[1]	38·3	22·1	6–c[2]	19·3

[1] Rape cake alone: the addition of potash and phosphates has very little effect.

[2] Rape cake + potash and phosphates, these being specially needed for mangolds.

[3] Dung + potash and phosphates: this yield is, however, almost the same as with dung alone.

The effect only lasts for one year at Rothamsted and no evidence has been obtained of any residual effect (Table XV).

[1] An interesting old account is given by Hannam in *Journ. Roy. Agric. Soc.*, 1848, IV. 177.

TABLE XV. *Immediate and subsequent effects of rape cake. Rothamsted, Little Hoosfield. Total produce per acre (unmanured* = 100)

	Swedes 1904	Barley 1905	Man-golds 1906	Spring Wheat 1907	Swedes 1908
Unmanured	100	100	100	100	100
Year of application	134	154	116	146	134
1st year after application	—	98	92	101	103
2nd ,, ,,	—	—	91	96	99
3rd ,, ,,	—	—	—	86	103

	Barley 1909	Wheat 1910	Man-golds 1911	Wheat 1912	Mean
Unmanured	100	100	100	100	100
Year of application	125	125	114	131	131
1st year after application	90	81	91	119	97
2nd ,, ,,	112	78	92	105	96
3rd ,, ,,	93	90	84	106	94

Castor meal is also used to some extent. Oil cakes residues play a very important part in Indian agriculture and not infrequently prove better and cheaper than artificial manures (p. 149).

Seaweed

Seaweed is one of the oldest manures known and has been in use since remote ages in the coastal districts of Great Britain. It is so important in Jersey that the dates for cutting are annually fixed and announced by the Court, while the collection, drying and stacking afford regular summer occupation to some of the

poorer people: in Scotland also the right to collect it sometimes forms part of the covenant with the landlord. Seaweed contains about the same amount of nitrogen as ordinary farm crops, and a considerably higher percentage of potash than these or the Zostera and other plants often collected with it. The different weeds vary, the long broad leaf-like *Laminaria* being richer than *Fucus*, the common bladder-wrack of the rocks. Further the weed cut or thrown up early in the year is richer than that obtained later in summer or autumn. The average composition of wet weed is usually[1]:

Water	Organic matter	Nitrogen	Potash (K_2O)	P_2O_5
70–80	13–20	0·3–0·8	0·8–1·5	0·02–0·17

It is thus very similar to farmyard manure except that it contains less phosphoric acid. On drying, however, a very rich manure is obtained which ought to be utilised to a greater extent than is done at present.

It is largely used for potatoes in Jersey and in Scotland, the dressings being from 25–30 tons in Ayrshire and up to 45 tons in Jersey: some artificials are also applied. In Thanet 10–15 tons per acre is applied to lucerne and to market garden crops.

Definite manurial trials with fresh seaweed as hauled up in farm carts have been made in Scotland by Hendrick[2] and in Ireland by the officers of the Department[3]. The general result is that fresh seaweed is not much inferior to dung, while there can be little doubt that dried weed powdered up would make an admirable concentrated fertiliser.

[1] See *Journ. Board of Agric.*, 1910, XVII. p. 458, for fuller details on the composition and use of seaweed as manure.

[2] *Trans. Highland and Agric. Soc.*, 1898, p. 118.

[3] *Journ. of the Dept. of Agric. and Tech. Instruction*, Jan. 1914.

(C) Waste Products from Manufactories and Towns

Shoddy

Shoddy is the waste material turned out from the Yorkshire mills which tear up old cloth and woollen rags and make them into new cloth; it consists of the fragments that are too small to be picked up by the machine. Three groups may be distinguished. The high grade contains 12 to 14 per cent. of nitrogen, it is pure and free from cotton or dirt, but is largely purchased for the manufacture of compound or patent manures.

Table XVI. *Effect of shoddy on crops. Rothamsted, Little Hoosfield. Total produce per acre (unmanured* = 100)

	Swedes 1904	Barley 1905	Man-golds 1906	Spring Wheat 1907	Swedes 1908
Unmanured	100	100	100	100	100
Year of application	137	170	140	173	130
1st year after application	—	142	136	144	147
2nd „ „	—	—	121	105	126
3rd „ „	—	—	—	108	108

	Barley 1909	Wheat 1910	Man-golds 1911	Wheat 1912	Swedes 1913	Mean
Unmanured	100	100	100	100	100	100
Year of application	118	135	126	117	135	138
1st year after application	103	93	120	123	119	125
2nd „ „	142	90	99	126	91	112
3rd „ „	116	100	99	108	71	101

The medium grade contains 5 to 8 per cent. of nitrogen and is considerably admixed with cotton, dirt and sometimes oil: larger supplies are available and it is much used in hop gardens. At Rothamsted remarkably good results have been obtained on farm crops, and the effect of the dressing even persists into the second and third years (Table XVI).

The lowest grade is sometimes very poor, containing only about 3 per cent. of nitrogen, and should only be purchased when it can be had cheaply.

Other waste products[1]. From time to time various nitrogenous or phosphatic substances are available as manure and can be purchased at fairly cheap rates. Their value depends on their composition and their mechanical condition: they should therefore only be purchased on analysis. The proper way of dealing with them would be to submit them to a preparatory grinding and mixing, but often the supplies are too small or too irregular to justify the erection of plant for the purpose.

Hair, calf hair, etc., contains about 10 per cent. of nitrogen but is very slow to decompose in the soil especially in its usual long state: it should be only used when it can be obtained very cheaply and is in fair mechanical condition.

Feathers containing about 9 per cent. of nitrogen are used with advantage in hop gardens, the small ones especially decomposing fairly quickly. On the other hand large feathers only break down slowly, the shafts especially taking a long time to decay.

Rabbit waste consists of the ears, feet, tail, etc., of the rabbit, and so far as the supply goes it is distinctly useful as manure and is improved by properly grinding.

[1] Described in more detail in Board of Agric. Leaflet, No. 175.

Leather waste. Boot leather waste has at times been offered to farmers, but it has never been shown to possess manurial value and should not be purchased, nor should it enter into the composition of a mixed manure. Unfortunately finely ground samples containing some 7 per cent. of nitrogen are periodically offered for sale at about 3*s*. or 4*s*. per unit, and there is reason to believe that they are sometimes used in compound and patent manures to give a high nitrogen content, and an undeserved appearance of richness. This is the more regrettable as leather might probably be made a useful manure by suitable treatment.

Soft leather scraps obtained from glove factories are in a different category, and find valuable application in market gardens in the glove districts of Worcestershire: they are put into the soil with the young sprouts, cabbages, etc., at the same time of setting out and afford a useful root run.

Soot. Soot owes its manurial value to three properties. It supplies nitrogen to the soil, a bushel of soot usually containing 1 lb. of nitrogen (mainly as sulphate of ammonia) normally worth about 7*d*. (p. 126). It contains some substance disagreeable to slugs and other pests, and it improves the physical conditions in the soil partly by ameliorating the texture and partly by the warming effect of its black colour. It is much used as a spring dressing for wheat, supplying both the nitrogen and the warmth that is then needed; and it is also used for hops in Kent, quantities being sent for the purpose from Manchester and other northern cities[1].

[1] Knecht has extracted a number of interesting compounds from Manchester soot, including a paraffin $C_{27}H_{56}$ that is also present in beeswax. *Proc. Manch. Lit. and Phil. Soc.*, 1905, p. 49.

Sewage sludges

Sewage sludges deserve special mention because the supply is considerable and is not likely to fall off in the future: they also have the advantage of returning to the land some of the fertilising materials that have been taken off to the cities. The sludge is usually prepared by some precipitating or settling process, and therefore contains only the insoluble compounds and not the soluble and valuable nitrates, ammonia, etc. This indeed is its weakness: it has been so well washed during the process of formation that it has lost much of its decomposable material.

Various experiments have frequently been made to ascertain the manurial value of sludge, but the results have not been very satisfactory. The usual course of events is that farmers are first induced to purchase it but finally have to be paid to take it away. Methods have therefore been devised for improving the sludge, perhaps the commonest being to add a certain proportion of lime and then to force the mass into presses when it forms a cake containing roughly 50 per cent. of water, 15 to 25 per cent. of organic matter and 25 to 35 per cent. of mineral matter much of which is lime, and about 1 per cent. each of nitrogen and of P_2O_5. Several of these pressed sludges were tested on field crops during the years 1905–8, but the results were not good: only in the wetter districts of the North of England did they seem to have much value[1]. In some places, *e.g.*, Glasgow, Kingston, etc., other

[1] 5th Report of the Sewage Commission, 8th Appendix, Cd. 4286, 1908. A good summary is given in *Journ. Board of Agric.*, 1908, xv. p. 690.

materials are added to enrich the sludge, whilst elsewhere a process is at work to extract the fat, grease, etc., which in modern times have become too precious to lose even in sewage.

These products are sent out in good mechanical condition ready for distribution: but some of them suffer from the drawback that they are sold at prices considerably in excess of their real value.

CHAPTER XII

THE PURCHASE AND USE OF ARTIFICIAL MANURES

THE British farmer has a fairly wide range of fertilisers to select from, and in addition he fertilises his land through the feeding stuffs purchased for his cattle. The supplies are regularised by the various syndicates, nevertheless there are market fluctuations of which farmers and co-operative societies should take advantage. Further, a large number of proprietary manures are on the market, the percentage analysis of which has to be declared[1], and it is therefore convenient to have a method by which one fertiliser can be compared with another to ascertain which is the cheaper.

The basis of comparison is the unit value. The unit value is the cost of 1 per cent. per ton, and it is obtained by dividing the cost of the manure by

[1] Under the Fertilisers and Feeding Stuffs Act, 1906, full details of which are given in the *Journ. Board of Agric.*, 1906–7, x. 13.

the percentage of nitrogen, potash or phosphate. Thus the unit value of nitrogen in nitrate of soda is obtained as follows:

Nitrate of soda contains 15 per cent. of nitrogen and costs £11 f.o.r.

$$\therefore \text{ 1 per cent. costs } \pounds\tfrac{11}{15} \text{ per ton} = 14s.\ 8d.$$

and this is the unit price or unit value. So the unit value of nitrogen in sulphate of ammonia is

$$\frac{\text{price per ton}}{\text{percentage of nitrogen}} = \frac{\pounds 13}{20} = 13s.$$

In this case the sulphate of ammonia is the cheaper and would be purchased unless there were any special reason for choosing the nitrate of soda.

The unit value of phosphate in superphosphate or in basic slag, and of potash in the various potash fertilisers, is obtained in the same way.

When manures contain two or more fertilising constituents it is obviously impossible to proceed entirely in this way, and certain conventions have to be adopted. It is assumed that the potash has the same value as in the potash fertilisers but that the phosphate has less value than in superphosphate, an assumption that is probably sound. The actual value assigned to the phosphate is usually about 1*s*. 3*d*. to 1*s*. 9*d*. according to the grade of the manure; guanos, fish and meat meal ranking higher than steamed bone flour. After allowing for these two constituents one can proceed to calculate the unit value of the nitrogen:

A Peruvian guano containing[1] 7 per cent. of ammonia, *i.e.*, 5·8 per cent. of nitrogen, 30 per cent. of phosphates and 2 of K_2O, was offered at £9. 12*s*. 6*d*. per ton f.o.r.

[1] The trade expression. See pp. 132 and 136.

	£	s.	d.
1 unit of phosphate is worth 1*s*. 9*d*.			
∴ 30 are worth	2	12	6
1 unit of K_2O is worth 4*s*. 6*d*.			
∴ 2 are worth		9	0
The phosphate and K_2O are worth	3	1	6
∴ For 5·8 per cent. of nitrogen the dealers are asking £9. 12*s*. 6*d*. less £3. 1*s*. 6*d*.	6	11	0

i.e., unit price asked = 22*s*. 7*d*.

This is higher than the price in nitrate of soda or sulphate of ammonia but the guano contains organic matter which is of considerable value to the soil.

The advantage of the unit system is that it at once enables a buyer to discriminate between a cheap and a costly article. The following is an actual illustration:

A proprietary manure containing 1·8 per cent. of nitrogen, 22 per cent. of phosphate, and 2 of K_2O, was offered at £5. 5*s*. per ton.

	£	s.	d.
22 units of phosphates are @ 1*s*. 5*d*. worth	1	11	0
2 ,, K_2O ,, ..		9	0
The phosphates and K_2O are worth	2	0	0
∴ For 1·8 per cent. of N the dealers are asking	3	5	0

i.e., unit price asked = 36*s*. 1*d*.

which is clearly excessive. A further instance of excessive price for low grade manures is given in Table XVII and others can be found in the agricultural journals[1].

[1] See Dr Voelcker's Reports in the *Journal of the Royal Agricultural Society*, and Board of Agric. Leaflet, No. 72.

Table XVII contains unit values of the constituents of the commoner fertilisers. The term unit *value* is not very happy because these are not the *value to the farmer*, but the price he is invited to pay, which may be a very different thing: unit price would probably be a better term.

TABLE XVII. *Unit value of nitrogen, potash and phosphoric acid in various fertilisers and manures. [These quotations refer to the period prior to the war: they are for manures delivered to buyer's station, and are of course liable to variation according to the state of the market.]*

	Percentage composition			Price per ton, Cash	Unit value of		
	N	phosphate	K_2O		N	phosphate	K_2O
Nitrate of soda	15	—	—	£11 10 0	15/4	—	—
Sulphate of ammonia	20	—	—	£12 10 0	12/6	—	—
Peruvian guano	6	30	2	£10 5 0	24/-	1/9	4/6
Fish ,,	9	8	—	£9 2 6	19/-	1/9	—
Meat ,,	6·5	17	—	£7 10 0	18/-	1/9	—
Rape cake	4·75	4	—	£6 0 0	23/-	1/6	—
Dried blood	12	—	—	£12	20/-	—	—
Horn	12	—	—	£12	20/-	—	—
Shoddy	12	—	—	£6	10/-	—	—
,,	5	—	—	40/-	8/-	—	—
Two low grade manures (*a*)	1·8	22	2	£5 5 0	36/1	1/5	4/6
(*b*)	2	4	—	£4 10 0	42/2	1/5	—
Superphosphate	—	30	—	55/-	—	1/10	—
Basic slag	—	24–42 20–34 soluble	—	27/- to 52/-	—	1/5	—
Sulphate of potash	—	—	48·5	£11 7 6	—	—	4/8
Kainit	—	—	12·0	57/6	—	—	4/9

Gardeners who buy in smaller lots may find it more convenient to work out prices per cwt. instead of per ton.

Many dealers give the percentages of *ammonia*

instead of nitrogen. Table XVIII is useful for the purpose of conversion:

TABLE XVIII. *Conversion of percentages of nitrogen to equivalent percentages of ammonia, and vice versa*

Nitrogen to ammonia		Ammonia to nitrogen	
Per cent. of nitrogen	Equivalent per cent. of ammonia	Per cent. of ammonia	Equivalent per cent. of nitrogen
1	1·2	1	0·8
2	2·4	2	1·6
3	3·6	3	2·5
4	4·8	4	3·3
5	6·1	5	4·1
6	7·3	6	5·0
7	8·5	7	5·8
8	9·7	8	6·6
9	10·9	9	7·4
10	12·1	10	8·2

Mixed manures and proprietary articles. A farmer who knows precisely what mixture of manures he wants can get it made up without difficulty by the merchant, but for those who are uncertain what to use, there are advantages in purchasing mixed manures and a number of good articles are on the market. Before these are bought, however, the unit prices should be worked out as shown above and compared with the current prices of nitrate of soda, fish and other guanos, superphosphate and sulphate of potash. Something must be allowed for the convenience of buying all the fertiliser in one consignment, and for the cost of mixing, but there should not be a great difference between the price asked and that at which a mixture of good fertilisers containing the same amounts of nitrogen, potash and phosphoric acid could be made

up. Especially should the farmer beware of specious claims to subtle properties not shown by analysis, sometimes made to explain excessive charges.

The unit system is not entirely satisfactory for mixed manures because the maker does not declare the components, and it is not possible to tell without an analysis whether he is getting his nitrogen from fine leather dust at a very low price per unit, from shoddy at 6*s*. or 7*s*. a unit, from meat meals at 12*s*. a unit or from blood or high grade guanos at 20*s*. a unit. The analyst should be asked whether any quantity of leather dust or other adulterant is present (see p. 175).

Manures for crops. No definite scheme for manuring crops can be given for universal use because of the varying factors of soil, climate, market prices, and available capital, but certain guiding principles hold fairly generally and can be adapted to each locality.

All of the fertilising constituents, nitrogen, potash, phosphoric acid, lime and organic matter must be applied to the land in the course of the rotation. The nitrogen being liable to loss should be distributed, a certain amount being added either each year or each alternate year: the other four constituents are less liable to loss and may be applied to any crop that is most convenient. The Saxmundham experiments show that equal financial returns are obtained wherever superphosphate is applied in the rotation, while nitrate of soda could not be used in this indiscriminate manner but gave better returns when applied to roots or wheat than to barley. In practice it is usual to give a good dressing to the root crop and lighter dressings to the intervening cereal crops. Care has to be taken, also,

to avoid unequal intervals between dunging and folding the land. The distribution of manure is often effected somewhat as follows:

The root crop receives a mixture of farmyard manure and a *complete* dressing of artificials: phosphates should preponderate in the mixture for swedes, turnips, rape, etc., while potash should form a larger proportion of the dressing given to mangolds, sugar beet, and potatoes.

The succeeding cereal crop may be wheat or oats, in which case it may need a little nitrogen in spring applied as nitrate of soda or of lime, sulphate of ammonia, etc.; in late districts or wet seasons superphosphate, etc., may be desirable to hasten ripening. When the roots have been folded and barley is to be grown, no nitrogen is needed but superphosphate must be applied to prevent rankness (see p. 133).

The seeds may receive lime, basic slag or potash; no nitrogen is usually necessary where the aftermath is folded off.

The grazing land should periodically receive basic slag alone, or basic slag and kainit, while land laid in for hay should in addition receive an annual dressing of a nitrogenous manure such as sulphate of ammonia, nitrate of soda, etc.: every four years or so, however, dung should be applied instead. Fig. 31 shows the results obtained at Rothamsted.

No general recipes can be given for the composition of manures. At one time it was supposed that the ideal mixture was that represented by the composition of the ash as showing what the plant had actually taken from the soil. This is now known to be incorrect: the need for manures is determined not by the

composition of the plant but by its habit of growth and the conditions under which it lives. On any particular

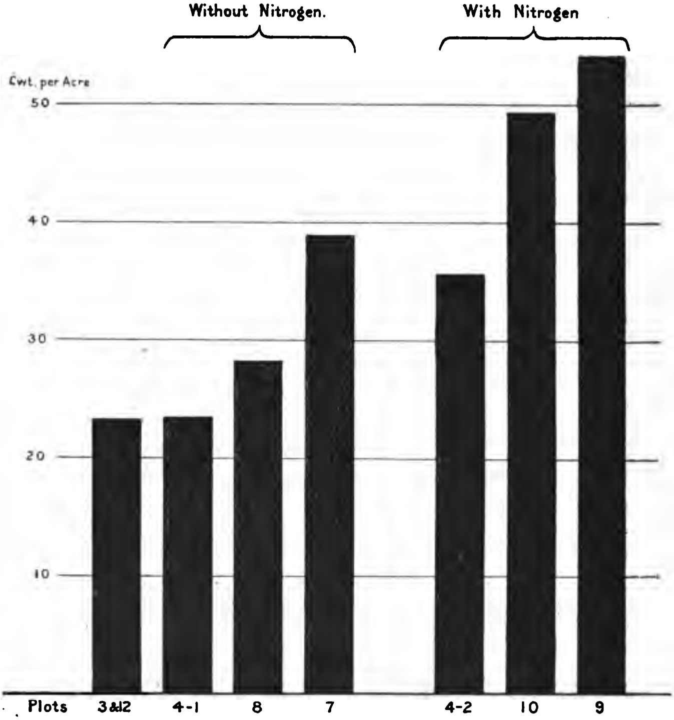


Fig. 31. Effect of manures on the yield of hay. The Park, Rothamsted. (Average 57 years, 1856–1912.)

Plots 3 & 12. Unmanured. 4–1. Superphosphate only.
Plot 8. Superphosphate, sodium and magnesium salts.
,, 7. ,, ,, ,, + potassium salts.
,, 4–2. Super and ammonium salts (86 lbs. N per acre).
,, 10. Super and ammonium salts + sodium and magnesium salts.
,, 9. Super and ammonium salts + sodium and magnesium salts + potassium salts.

farm the most suitable mixtures can only be discovered by trial; several recipes can be drawn up on the

basis of the information already given, and the most suitable ones tested. The problem is considerably simplified in counties where a soil survey has been made or systematic field experiments conducted.

The actual amount of the mixtures that may be used is regulated by the following general rule:

Additional manure usually gives extra crops (provided it is suitable) but beyond a certain point the yield *per cwt. of manure* falls off, so that the extra crop is obtained at higher cost per ton or per bushel than a smaller crop would be. This is known as the Law of Diminishing Returns, and it holds very generally; it is just as true for the horse power of a motor cycle as of the yield of wheat. Table XIX gives an illustration from the Broadbalk plots at Rothamsted:

TABLE XIX. *Influence of increasing dressings of nitrogenous manures on yield of wheat; Broadbalk field. Average* 61 *years*, 1852–1912

	Grain bushels	Increase per 200 lbs. ammonium salts bushels	Straw cwts.	Increase per 200 lbs. ammonium salts cwts.
Mineral manure alone	14·5	—	12·1	—
Mineral manure + 200 lbs. ammonium salts	23·2	8·7	21·4	9·3
Mineral manure + 400 lbs. ammonium salts	32·1	8·9	32·9	11·5
Mineral manure + 600 lbs. ammonium salts	36·6	4·5	41·1	8·2

(See Figs. 2 and 32.)

Thus for the first 400 lbs. of ammonium salts each 100 lbs. gives an additional 4½ bushels of wheat

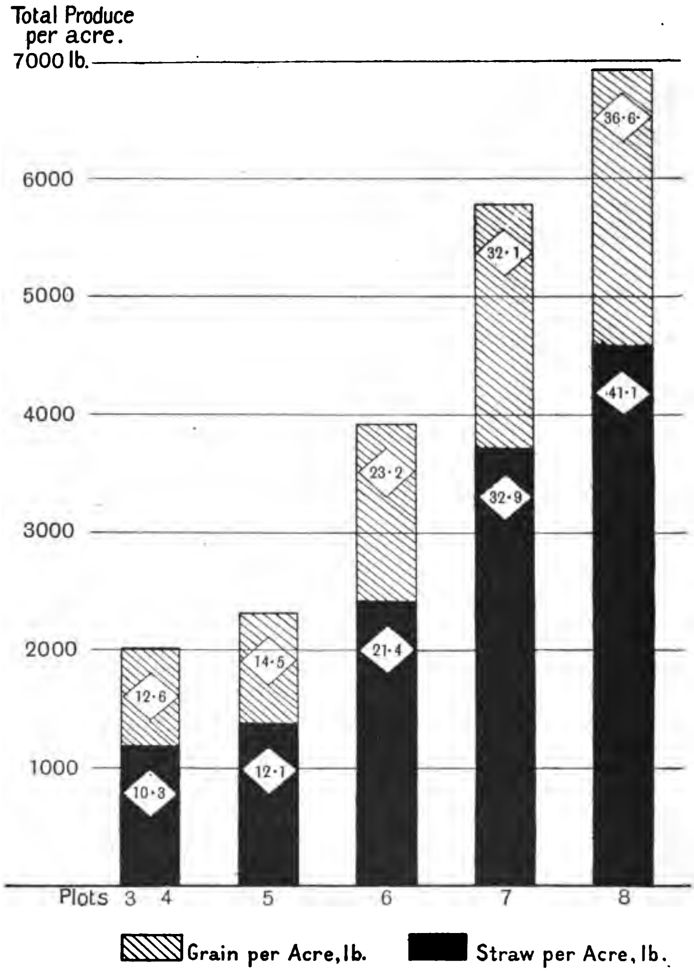


Fig. 32. Diagram showing effect of increasing amounts of nitrogenous manures on the yield of wheat. Broadbalk field, Rothamsted. (Average 61 years, 1852–1912.)

Plots 3 & 4. Unmanured.

Plot 5. Potash and phosphates but no nitrogenous manure.

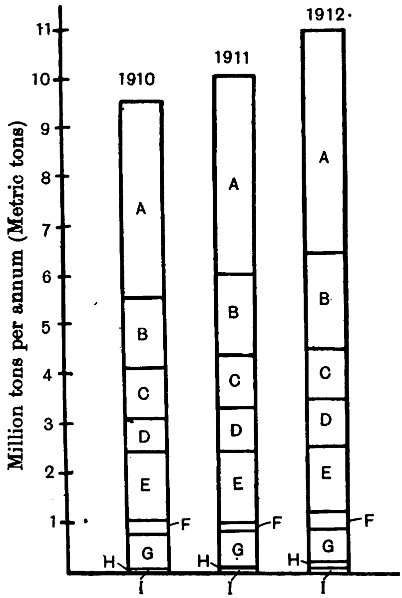
„ 6. Potash and phosphates and sulphate of ammonia containing 43 lbs. N per acre.

„ 7. Potash and phosphates and sulphate of ammonia containing 86 lbs. N per acre.

„ 8. Potash and phosphates and sulphate of ammonia containing 129 lbs. N per acre.

The columns represent total produce per acre, but the figures in the diamond spaces give bushels of grain and cwts. of straw per acre.

and 5 cwts. of straw, together worth about 21*s.*: the dressing has therefore been profitable: when more ammonium salts are added the increase given by each 100 lbs. is worth only about 12*s.* which is not profitable. On other soils the point of diminishing profit



A = Superphosphate.
B = Mineral phosphate.
C = Potash salts.
D = Basic slag.
E = Nitrate of soda.
F = Sulphate of ammonia.
G = Potash salts (as pure potash).
H = Artificial nitrogenous manures (nitrolim, nitrate of lime).
I = Peruvian guano.

Fig. 33. The world's annual consumption of artificial fertilisers (from *Production et Consommation des Engrais Chimiques*, Institut International d'Agriculture, Rome, 1914).

Each of the above columns is to be read from the base line.

may come somewhere else, but there always is such a point, and the farmer must be careful not to pass it.

Application of artificial manures. The following points are to be remembered:

Nitrate of soda should go on as a top dressing *after* the crop is up.

Sulphate of ammonia should go on *just before* the crop is up except in the case of wheat and winter oats, when it may be added as a top dressing in spring.

Superphosphate, potassic fertilisers and slag can go on whenever convenient but should be applied not later than early spring.

Labour may be saved by mixing the fertilisers when two or more are to be drilled in or distributed, but the following should not be mixed by the farmer:

Basic slag, lime or chalk with sulphate of ammonia.

Dissolved bones with nitrate of soda.

The following can be mixed if they are applied without delay:

Superphosphate with nitrate of soda; dissolved bones with potash manures; basic slag with kainit.

All artificial manures have to be stored in a dry place and mixed on a hard dry floor.

Fig. 33 shows the amounts of artificial manures now produced annually.

CHAPTER XIII

CHALK, LIMESTONE AND LIME

CHALK is one of the oldest fertilisers in this country and was used by the ancient Britons in much the same way as is still done in parts of Hertfordshire to-day[1].

It has two main types of action: it supplies basic material which is very necessary for the soil, and it

[1] See the author's *Fertility of the Soil*, Cambridge Manuals, for fuller details.

improves the physical condition. The necessity for a base is very definitely marked: in its absence the soil becomes "sour." Such soil is not well suited to plant growth and will not carry luxuriant crops: certain weeds, however, grow well, notably sorrel on heavy land and spurry on light land. "Sourness" often arises through neglect, though it also comes when land lies waterlogged for a long time. The distinction between "sour" soil and sweet soil is very great, for "sourness" is not only inimical to plants but also to micro-organisms, and the differences seen in vegetation are probably no greater than those existing in the microscopic population of the two soils. Just as certain weeds turn up most commonly on "sour" soils so also do certain micro-organisms, such as *Plasmodiophora* which causes finger and toe in turnips and other plants of the Brassica tribe. Whatever the cause, the trouble can be put right by suitable dressings of chalk or lime.

The alteration in physical condition has been more fully studied, but is still somewhat obscure. It is mainly attributed to the conversion of the deflocculated or sticky clay into the flocculated form. While either lime or chalk is in practice equally effective in bringing about this change they are not the actual agents concerned in the deflocculation, indeed chalk is inert while lime itself has the reverse effect, changing the flocculated to deflocculated clay (p. 23). The action is determined by the presence of a little carbonic acid which always occurs in the soil.

Of course where the bad physical condition is due to other causes chalk may be ineffective to put it right. The silty clays form a case in point (p. 103).

Lime differs from chalk in two important directions. It dissolves some of the organic compounds in the soil and apparently effects a certain amount of decomposition. This can be demonstrated by mixing 50 grams soil with ½ to 1 gram of quick lime, adding 200 c.c. of water and shaking well. An extract tinged with yellow or brown is obtained, which on analysis is found to contain organic matter, potassium, and other substances. Thus addition of excess of lime to the soil may result in excessive decomposition and the loss of valuable plant nutrients.

> "Lime and lime without manure
> Will make both soil and farmer poor,"

as the old saying goes. One result of this decomposition apparently is to aid the work of the soil bacteria and to increase the production of plant food. The second difference between lime and chalk is that when added in sufficient quantity quick lime partially sterilises the soil, killing many of the bacteria, protozoa and other organisms[1]; later on the bacterial numbers rise very considerably, and produce increased quantities of ammonia and nitrates; this stage coincides with the time at which the lime is converted into calcium carbonate.

In common with many other substances lime and calcium bicarbonate are absorbed from their solution by certain constituents of the soil, and displace some of the substances previously absorbed. Thus lime causes the liberation of a certain amount of potash from the soil so that a dressing of lime is often equivalent to a dressing of potash.

[1] Hutchinson and MacLennan, *Journ. Agric. Sci.*, 1914, VI. 302.

Quantity required. Lime and chalk are both converted into calcium bicarbonate in the soil and are then liable to be washed out. There are sources of production in the soil, but the general tendency is for losses to preponderate, and at Rothamsted they amount to some 800 lbs. of lime (CaO) per acre per annum on arable land but less on grass land; very similar results were obtained by Hopkins in Illinois. This amount would be returned to the soil in 8 cwts. of good burnt lime (85 per cent. CaO) or 15 cwts. of limestone or chalk and if this dressing were annually given per acre there would be no diminution in the stock. Lime and limestone can readily be had in a finely divided state, and can be put on with a distributor as a regular proceeding: 1 ton of lime or 2 tons of limestone are suitable quantities. Cob lime may be used instead of ground lime and is cheaper, but on the other hand it is more costly to spread. Chalk is not easy to grind and is usually applied in lumps, less than 20 or 30 tons per acre cannot conveniently be added so that regular dressings are not common, and it is only put on at long intervals when other work allows, which means in practice that chalking is commonly neglected. There is no doubt that neither liming nor chalking is done as regularly as it should be, and that fertility is suffering in consequence.

One of the first steps to be taken in improving run out land is to apply lime or chalk and in some countries facilities for doing this are afforded by the State: *e.g.*, in Illinois limestone is ground at the State Penitentiaries and sold at a very cheap rate to farmers. Clay soils in particular stand in need of lime, because of their tendency to become deflocculated,

but sandy soils also require dressings because they readily become sour.

Lime has usually proved inferior to ground limestone in the long series of experiments at the Maryland Experiment Station[1] and in the still longer series at the Pennsylvania Experiment Station[2]. Milburn and Gaut obtained similar results in the Lancashire trials[3]. This inferiority, however, is sometimes outweighed by another consideration: 1 cwt. of lime is equivalent to 1¾ cwts. of ground limestone and this difference becomes important where freight is high. Limestone can be kept in bags but lime must be used as soon as possible. Instead of lime the farmer may sometimes be able to buy lime ashes cheaply, but he should only do this after an analysis has been made.

Ground limestone or lime should be applied in autumn or early spring and may with advantage be put on to the clover crop or to turnips: both crops respond well, indeed clover (and other leguminosæ) will often fail when lime is deficient in the soil while turnips or swedes become liable to finger and toe. The potato crop, however, does not seem to benefit, and the liability to scab is considered by some practical men to increase after lime is applied, but more definite experiments are needed on the subject. Rhubarb does not usually benefit.

Chalk should be applied as early as possible in autumn so that winter frosts can disintegrate it and allow of a better distribution later on by means of the harrow: it is most conveniently applied to the leys.

Even where limestone does not increase the yield

[1] Bull. 110, 1906. [2] Annual Report, 1907–8, p. 93.

[3] Lancashire C. C., *Bull.* 24, 1914.

of hay or grass land it may improve the herbage: this happened at Garforth, where sorrel was crowded out, and also in the Lancashire trials, where the bent grass was practically exterminated while the rye grass practically doubled.

Many limestones contain magnesia and are therefore considered to be risky in use, but no British experiments have confirmed this view nor have those at New Jersey[1].

Mortar rubbish contains considerable quantities of calcium carbonate and should always be applied to gardens whenever it can be obtained: it not only benefits the soil but in virtue of its sand it helps the development of fibrous root.

Gas lime may be used with advantage when it can be obtained cheaply, but it can only be applied in winter. The modern variety is less offensive than the old fashioned "Blue Billy" but it is less useful as an insecticide in horticultural work.

[1] *New Jersey Bulletin*, No. 267, 1914.

APPENDIX

The Methods of Soil Analysis

How to take the sample of soil. Owing to the variation in composition of the soil at different depths it is particularly necessary that the sample should always be taken to the same depth and with a tool making a clean vertical cut. Samples taken with a spade are of very doubtful value and do not justify any lengthy examination. The simplest tool is shown in Fig. 34 and consists of a steel tube 2 in. in diameter and 12 in. long, with a $\frac{3}{4}$ in. slit cut along its length and all its edges sharpened. The tube is fixed on to a vertical steel rod bent at the end to a ring 2 in. in diameter, through which a stout wooden handle passes. A mark is made 9 in. from the bottom so that the boring process can be stopped as soon as this depth is reached. On withdrawing the tool the core of soil is removed by a pointed iron rod. Five or six samples should be taken along lines crossing the field so as to get as representative a sample as possible; the whole bulk must then be sent to the laboratory. The student should carefully learn how to do this so that he can take samples for himself. Samples should not be taken from freshly ploughed or recently manured land.

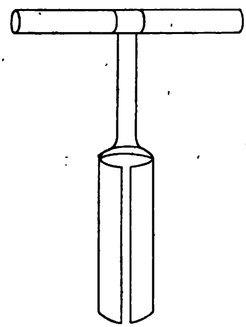


Fig. 34. Soil borer.

The analysis. On arrival at the laboratory the soil is spread out to dry, and is then pounded up with a wooden pestle and passed through a 3 mm. sieve. The stones that do not pass through, and the fine earth that does, are separately weighed, and the proportion of stones to 100 of fine earth is calculated. Subsequent analytical operations are made on the fine earth.

Moisture. Four or five grams of the soil are dried at 100° C. till there is no further change in weight.

Organic matter. No accurate method of estimation has yet been devised. It is usual to ignite at low redness the sample dried

as above. The loss includes organic matter, water not given off at 100° C., and carbon dioxide from the carbonates; allowance may be made for the latter, but not for the combined water.

Total nitrogen. Kjeldahl's method is almost invariably adopted. About 25–30 grams of soil are ground up finely in an iron mortar; 10–15 grams are then heated in a Kjeldahl flask with 20–25 c.c. of strong sulphuric acid for ¾ hour; then 5 grams of potassium sulphate are added, and shortly after a crystal of copper sulphate. The heating is continued till all the black colour has gone. Then cool and dilute the mixture, transfer the fluid part to a distillation flask, but leave as much as possible of the sand behind, and wash well to remove all the adhering liquid. Add saturated soda solution till the liquid is strongly alkaline, distil and collect the ammonia in standard acid.

Nitrate. Place 100 grams of soil in a stoppered bottle and shake well with 100 c.c. of water. After waiting for the heavier particles to settle, decant some of the extract through a filter. Evaporate 10 c.c. of the filtrate to dryness on a water-bath and add 1 c.c. of phenol sulphonic acid (made by adding 55·5 c.c. of strong pure H_2SO_4 to 4·5 c.c. of water containing 9 grams of phenol) to the residue, stirring well with a small glass rod. After 10 minutes dilute with 25 c.c. of water and add ammonia or caustic potash till alkaline to litmus paper. If nitrate is present the solution becomes bright yellow, the depth of the colour being proportional to the amount of nitrate. The colour should be compared with that produced by 10 c.c. of a solution of nitrate of soda containing 10 parts of nitrogen per million, *i.e.*, ·06 gram of the salt per litre. A safety pipette should be used for the phenol sulphonic acid.

For more accurate work reduce the extract with a zinc-copper couple, distil off the ammonia with standard acid and titrate.

Carbonates are determined by treating a weighed quantity of the soil with dilute sulphuric acid and estimating the carbon dioxide evolved. Large quantities can be determined rapidly and with sufficient accuracy by the Scheibler apparatus, but much better results are obtained by absorbing the CO_2 in potash and determining the amount by titration. A simple apparatus is described by Hutchinson and MacLennan in *Journ. Agric. Science*, 1914, vol. VI. p. 323.

Mineral substances. Complete analysis of a soil after the silicates have been decomposed and the silica volatilised by treatment with hydrofluoric acid is only rarely attempted. The British method, adopted by the Agricultural Education Association, is thus described by Hall: "20 grams of the powdered soil are placed in a flask of Jena glass, covered with about 70 c.c. of strong hydrochloric acid, and boiled for a short time over a naked flame to bring it to constant strength. The acid will now contain about 20·2 per cent. of pure hydrogen chloride. The flask is loosely stoppered, placed on the water-bath, and the contents allowed to digest for about forty-eight hours. The solution is then cooled, diluted, and filtered. The washed residue is dried and weighed as the material insoluble in acids. The solution is made up to 250 c.c. and aliquot portions are taken for the various determinations. The analytical operations are carried out in the usual manner, but special care must be taken to free the solution from silica or organic matter." (*The Soil.*) As a rule only potash and phosphoric acid are determined, but where other bases are wanted they are estimated in the usual way.

Potash. 50–100 c.c. of the solution are evaporated to dryness after addition of 0·5 gram of pure $CaCO_3$ if the original soil did not effervesce when HCl was added.

Add 10 c.c. of 5 per cent. baryta solution, evaporate to dryness, ignite and take up with water, add 2·5 c.c. perchloric acid (sp. gr. 1·12), concentrate till dense fumes are given off, allow to cool, add 20 c.c. 95 per cent. alcohol and stir. Decant off the clear alcohol, add 40 c.c. alcohol containing 0·2 per cent. perchloric acid, transfer to a tared filter paper, wash with 50–100 c.c. of 95 per cent. alcohol till the runnings are no longer acid, dry at 100°, and weigh as $KClO_4$.

Phosphoric acid. The charred residue from which the potassium chloride has been removed is now extracted with hot dilute H_2SO_4, the filtrate and washings amounting to about 110 c.c. Add 25 c.c. of ammonium nitrate solution. Warm to 55° C., add 25 c.c. ammonium molybdate solution also at 55°, stir, allow to cool and filter after standing two hours. Decant through a filter: wash by decantation with 2 per cent. $NaNO_3$ till the washings are neutral, transfer the precipitate to the beaker used for the precipitation, and add a known volume of standard alkali so that the precipitate

completely dissolves. Measure the excess by titration using phenolphthalein as indicator. 1 c.c. of N/10 alkali = ·0003004 gm. P_2O_5.

Available potash and phosphoric acid. Dyer's directions are as follows: 200 grams dry soil are placed in a Winchester quart bottle with 2 litres of distilled water in which are dissolved 20 grams of pure citric acid. The soil is allowed to remain in contact with the solution at ordinary temperatures for seven days, and is shaken a number of times each day. The solution is then filtered, and 500 c.c. taken for each determination; this is evaporated to dryness, and gently incinerated at a low temperature. The residue is dissolved in hydrochloric acid, evaporated to dryness, redissolved, and filtered; in the filtrate the potash is determined as above. For the phosphoric acid determination the last solution is made as before, with the nitric acid; then proceed as above.

Mechanical analysis. 1. Ten grams of the air-dry earth, which has passed a 3 mm. sieve, are weighed out into a porcelain basin and worked up with 100 c.c. of N/5 hydrochloric acid, the acid being renewed if much calcium carbonate is present. After standing in contact with the acid for one hour, the whole is thrown upon a dried, tared filter and washed until free of acid. The filter and its contents are dried and weighed. The loss represents hygroscopic moisture and material dissolved by the acid.

2. The soil is now washed off the filter with dilute ammoniacal water on to a small sieve of 100 meshes to the linear inch, the portion passing through being collected in a beaker marked at 10, 8·5 and 7·5 cm. respectively from the bottom. The portion which remains upon the sieve is dried and weighed. It is then divided into "fine gravel" and "coarse sand" by means of a sieve with round holes of 1 mm. diameter. The portion which does not pass this sieve is the "fine gravel." This should be dried and weighed. The difference gives the "coarse sand." If required, both these fractions can also be weighed after ignition.

3. The portion which passed the sieve of 100 meshes per linear inch is well worked up with a rubber pestle (made by inserting a glass rod as handle into an inverted rubber stopper), and the beaker filled up to the 8·5 cm. mark and allowed to stand twenty-four hours. The ammoniacal liquid which contains the "clay" is then decanted off into a Winchester quart. This operation is

repeated as long as any matter remains in suspension for twenty-four hours. The liquid containing the "clay" is flocculated with hydrochloric acid. The dried residue consists of "clay" and "soluble humus." After ignition the residue gives the "clay" and the loss on ignition the "soluble humus."

4. The sediment from which the "clay" has been removed is worked up as before in the beaker, which is filled to the 10 cm. mark and allowed to stand for 100 seconds. The operation is repeated till the "fine sand" settled in 100 seconds is clean, when it is collected, dried and weighed.

5. The turbid liquid poured off from the "fine sand" is collected in a Winchester quart, or other suitable vessel, allowed to settle, and the clear liquid syphoned or decanted off. The sediment is then washed into the marked beaker and made up to the 7·5 cm. mark. After stirring, it is allowed to settle for twelve and a half minutes; and the liquid decanted off. The operation is then repeated as before till all the sediment sinks in twelve and a half minutes leaving the liquid quite clear. The sediment obtained is the "silt" which is dried and weighed as usual. The liquid contains the "fine silt," which, when it has settled down, can be separated by decanting off the clear liquid and dried and weighed.

6. Determinations are made of the "moisture" and "loss on ignition" of another 10 grams of the air-dry earth. The sum of the weights of the fractions after ignition + loss on ignition + moisture + material dissolved in weak acid should approximate to 10 grams. The sizes of the particles thus sorted out are as follows:

Fine gravel	Above 1 mm.
Coarse sand	1 to 0·2 mm.
Fine sand	0·2 to 0·04 mm.
Silt	0·04 to 0·01 mm.
Fine silt	0·01 to 0·002 mm.
Clay	Below 0·002 mm.

Analysis of manures

The following are the official methods commonly adopted in this country:

Thoroughly mix the sample, and if possible, pass it through

a 1 mm. sieve. The percentage of moisture is determined by drying a weighed sample at 100° C.

NITROGEN. (*a*) *In the absence of nitrates and ammonium salts.* A weighed quantity of the sample is put into a Kjeldahl flask with 10 grm. of potassium sulphate and 25 c.c. of concentrated sulphuric acid; the flask is heated till the contents become colourless or of a light straw colour. The operation may be accelerated by adding a small crystal of copper sulphate or a globule of mercury to the liquid in the digestion flask. During the process the nitrogen compounds are converted into ammonia, the amount of which is determined by distillation into standard acid after liberation with alkali, and, where mercury has been used, with the addition also of sodium or potassium sulphide solution. A blank experiment, using 1 gram of pure sugar in place of the sample, is made in order to give the amount of nitrogen present as impurity in the reagents used, which amount must be deducted from the quantity found in the first experiment.

(*b*) *In presence of nitrates.* A weighed sample is put into the Kjeldahl flask with 30 c.c. of concentrated sulphuric acid, 1 gram of salicylic acid is added, and the flask shaken at intervals, but kept cool; then 5 grm. of sodium thiosulphate and 10 grm. of potassium sulphate are put in, and the flask heated till the contents are colourless or nearly so. The rest of the procedure is as before.

(*c*) *Nitrogen as ammonia.* Alkali is added, and the ammonia is distilled into standard acid as above.

(*d*) *Nitrogen as nitrates, ammonia and organic nitrogen being absent.* 1 grm. of the sample is placed in a 500 c.c. Erlenmeyer flask with 50 c.c. of water. 10 grm. of reduced iron and 20 c.c. of sulphuric acid of 1·35 sp. gr. are added. The flask is closed with a rubber stopper pierced with a thistle tube the head of which is half-filled with glass beads. The liquid is boiled for five minutes and the flask is then removed from the flame, any liquid that may have accumulated among the beads being rinsed back into the flask with water. The solution is boiled for three minutes more, and the beads again washed with a little water. The ammonia is then distilled off and estimated as before.

PHOSPHATES. (*a*) *Soluble in water.* 20 grm. of the sample are continuously shaken for thirty minutes in a litre flask with 800 c.c. of water. The flask is then filled to the mark, again shaken,

and the contents filtered. 50 c.c. of the filtrate are boiled with 20 c.c. of concentrated nitric acid, and the phosphoric acid determined by the molybdate method below.

(*b*) *Soluble in 2 per cent. citric acid solution.* 5 grm. of the sample are put into a stoppered bottle of about 1 litre capacity, and 500 c.c. of a solution of citric acid, containing 10 grm. of the crystallised acid, added. The bottle is shaken in a mechanical shaker for thirty minutes. The solution is then poured all at once on to a large folded filter, and the filtrate if not clear, passed through the same paper again. 50 c.c. of the filtrate are then taken and treated as directed below.

(*c*) *Total phosphoric acid.* The nitric acid solution of a weighed quantity of the sample, after destruction of the organic matter if necessary, and removal of the silica by suitable means, is treated as below.

(*d*) *The molybdate method.* To the solution obtained in (*a*), (*b*) or (*c*), which should contain ·1 to ·2 grm. of P_2O_5, 100 to 150 c.c. of molybdic acid solution are added, the whole warmed to 70° C. in a water-bath for 15 minutes, allowed to cool, and filtered. The precipitate is washed first by decantation and afterwards on the filter paper with 1 per cent. nitric acid; the filtrate and washings are set aside and tested with more molybdic acid. The precipitate is dissolved in cold 2 per cent. ammonia solution, about 100 c.c. being used for the purpose. 15 to 20 c.c. of magnesia mixture are then added, drop by drop with constant stirring. After standing two hours, with occasional stirring, the precipitate is filtered off, washed with 2 per cent. ammonia, dried, ignited, and weighed as magnesium pyrophosphate.

The molybdic acid solution. 125 grm. of molybdic acid and 100 c.c. of water are placed in a litre flask, and the acid dissolved by the addition, while shaking, of 300 c.c. of 8 per cent. ammonia. 400 grm. of ammonium nitrate are added, the solution is made up to the mark with water, and the whole added to 1 litre of nitric acid (sp. gr. 1·19). It is maintained at about 35° C. for twenty-four hours and then filtered.

Magnesia mixture. 110 grm. of crystallised magnesium chloride and 140 grm. of ammonium chloride are dissolved in 1300 c.c. of water. 700 c.c. of 8 per cent. ammonia are added, and the whole allowed to stand for several days and filtered.

Ammonia solutions. (1) 8 per cent. 1 volume of ammonia solution of sp. gr. ·880 is mixed with 3 volumes of water and the solution adjusted by addition of more water or ammonia till the sp. gr. is ·967.

(2) 2 per cent. 1 volume of 8 per cent. ammonia is mixed with 3 volumes of water.

(This is the official method: the titration method given on p. 196 is simpler and equally accurate.)

POTASH. (*a*) *Muriate, free from sulphate.* A weighed quantity of the sample—5 grm. of a high-grade, 10 grm. of a low-grade muriate—is dissolved in water, and the solution, filtered if necessary, made up to 500 c.c. To 50 c.c. of this a few drops of hydrochloric acid and 10 to 20 c.c. of a solution of 10 grm. of platinic chloride in 100 c.c. water are added. Evaporate over the water-bath to a syrup, treat with alcohol of sp. gr. ·864. Collect the precipitate on a weighed filter paper, wash with alcohol as above, dry at 100° C., and weigh.

(*b*) *Salts containing sulphate.* Boil a weighed quantity of the sample (5 to 10 grm.) with about 300 c.c. water and 20 c.c. hydrochloric acid in a 500 c.c. flask. Barium chloride is added drop by drop till precipitation of the sulphuric acid is complete. Any excess of barium chloride is then removed by careful addition of sulphuric acid. Cool, and make up to 500 c.c. A portion of the solution is filtered, the precipitate washed, and the potassium in 50 c.c. of the filtrate determined as above.

(This is the official method: the perchlorate method on p. 196 is simpler and equally accurate.)

GUANOS, MIXED FERTILISERS, ETC. 10 grm. of the sample are gently ignited to destroy organic matter, heated for 10 minutes with 100 c.c. of concentrated hydrochloric acid, and finally boiled with about 300 c.c. water. Filter into a 500 c.c. flask, raise to the boiling point, and add a slight excess of powdered barium hydrate. Cool, make up to 500 c.c., and filter. To 250 c.c. of the filtrate add ammonium hydrate and ammonium carbonate, and then, while boiling, a little powdered ammonium oxalate. Cool, make up to 500 c.c., and filter. Evaporate 100 c.c. of the filtrate in a platinum dish, heat the residue first in an air-bath and then very gently over a low flame till all volatile matter is driven off, but keep the temperature below dull redness. Dissolve in hot water, filter and wash, determine the potash in the filtrate as above.

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